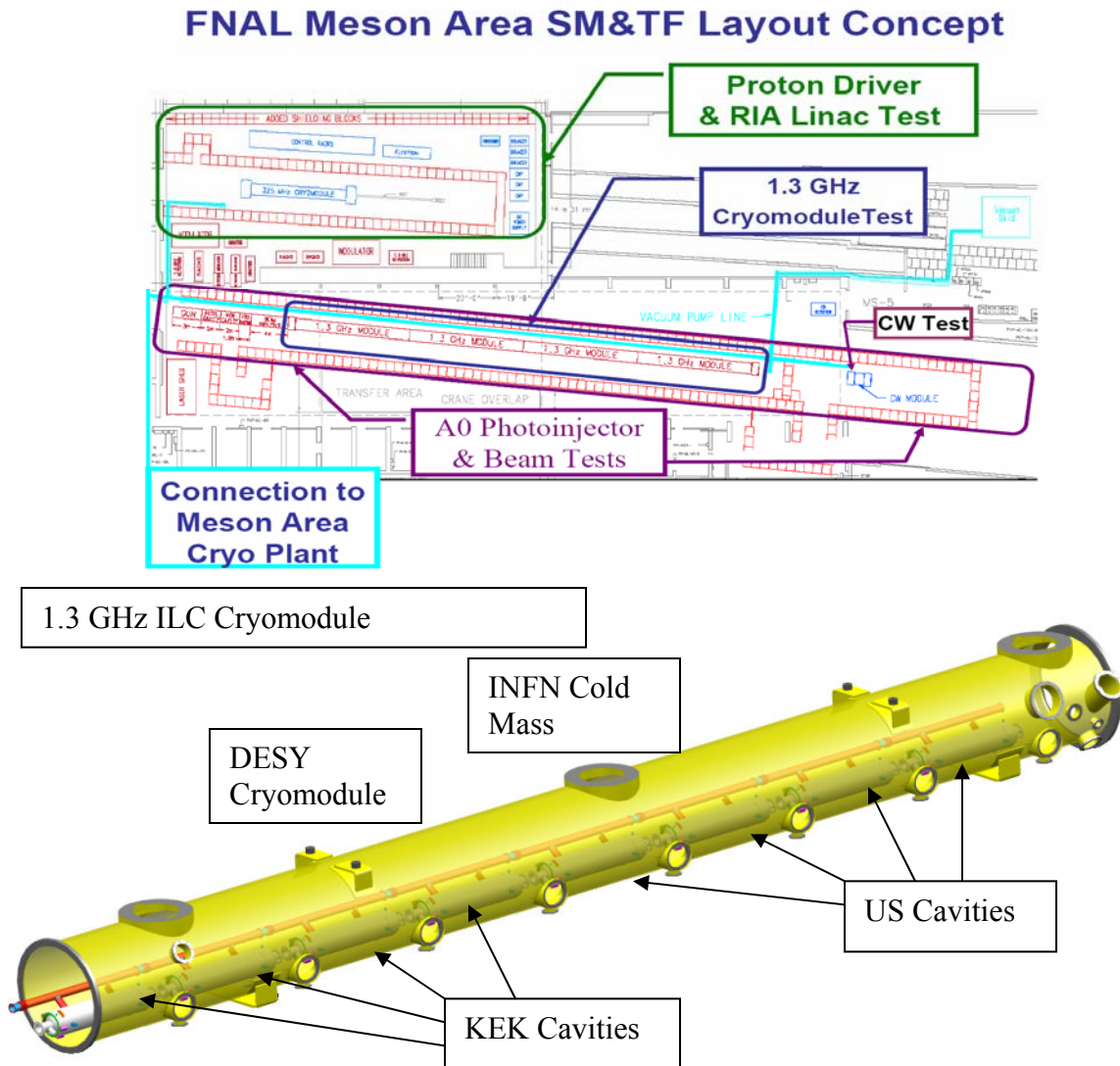


# Superconducting Module & Test Facility (SMTF)



The SMTF proposal is to develop U.S. Capabilities in high gradient and high Q superconducting accelerating structures in support of the International Linear Collider, Proton Driver, RIA, 4th Generation Light Sources, electron coolers, lepton-heavy ion collider, and other accelerator projects of interest to U.S and the world physics community.

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### 14. Summary

# 1. Executive Summary

This proposal describes a new US initiative to establish a superconducting radio-frequency (SRF) accelerator facility at Fermilab. The facility would provide the primary development and testing forum for major SRF-based projects in high energy physics, most notably the International Linear Collider (ILC) and Fermilab Proton Driver (PD) at Fermilab, as well as complement the existing and planned SRF facilities at other laboratories for nuclear physics, materials, and life sciences. Superconducting radio frequency cavity technology has advanced greatly in the past decade, so much so that an international panel recently recommended adopting SRF technology to accelerate the electron and positron beams of the International Linear Collider. In fact, nearly all new initiatives for electron, ion and proton sources incorporate superconducting cavities. These projects place increasing demands on the performance of SRF, and on the ability to produce SRF components in large quantities at lower costs. This challenge has not yet attracted US industry, because of the high initial investment cost in the technical infrastructure, and in training an expert work force in cryogenics and materials processing. By creating a shared infrastructure, the collaborators would benefit from the oversight and resources of a major laboratory, would avoid needless and costly duplication of resources, and would create the sort of scientific synergy that would assure success.

The centerpiece of this proposal is the *Superconducting Module and Test Facility*, or *SMTF*, that would be located at Fermilab, and that would provide test areas with cryogenics, high-power RF sources, beams and other required infrastructure for operating and testing a wide range of superconducting modules (cryomodules), along with a prototype factory for assembling SRF modules of various types. The largest of these test areas would have electron beam capability to allow full evaluation of cryomodule performance, and would support an ongoing program of beam dynamics studies. Institutions involved in the ILC, the Rare Isotope Accelerator (RIA), improvements to existing or planned electron beam accelerators and storage rings, the Fermilab Proton Driver, high-energy electron cooling and various fourth-generation light sources have all expressed strong interest in using such a facility and in working together on the development of their SRF systems.

The SMTF is not meant to replace infrastructure and capabilities that already exist or are planned at other U.S. laboratories and universities, but to expand R&D capabilities in an efficient manner to meet increasing demands. In particular, it is envisioned that one of the test areas would essentially be dedicated to testing the 1.3 GHz cryomodules that are required for both the ILC and the Fermilab Proton Driver. In this proposal, it is assumed that Fermilab would be the central laboratory for coordinating the ILC development of these components in the U.S. and would manage a collaboration of universities and laboratories (e.g., Cornell and JLab) and international ILC members (e.g., DESY and KEK) and industrial partners to develop the capabilities in the U.S. to build high performance cryomodules, which are presently built only in Europe.

The cavity development program for the other SRF projects would be led by collaborating institutions and projects, although there would be sharing of infrastructure to reduce costs. The programs and operational priorities at SMTF would be directed by an Institutional Board modeled on those successfully used for large particle physics collaborations (eg. CDF) and the TESLA Test Facility (TTF) at DESY. This board, which is now assembled, has representatives from the member institutions and the various SRF projects. There would be two co-spokespersons of this board that would act as leaders of the collaborating institutions in scientific and technical considerations related to the design, construction and operation of SMTF, and would represent the collaboration to all supporting funding agencies. The actual operation of SMTF, including the associated cavity and cryomodule development infrastructure, would be managed by FNAL. Formal MOUs would be developed between Fermilab and the participating laboratories and universities for these programs. Strong international cooperation and involvement at SMTF is anticipated with DESY, the TESLA collaboration, INFN, KEK, India, and others.

It is proposed that the SMTF would be constructed in phases beginning in 2005 and proceeding through the end of the decade. These phases would correspond to expanding the testing capabilities and SRF development infrastructure at FNAL. The initial tasks include the clean-up of the Meson East area and the establishment of the test areas, each with appropriate shielding, cryogenic capability and AC power for the RF sources. Also, the current A0 photo-injector at FNAL would be upgraded and moved to the ILC test area. For the ILC program that is proposed, the final assembly of the cavities into cryomodules would take place in clean room facilities constructed at Fermilab that would also support other projects, including SRF materials research.

Some of the program goals of projects that would use SMTF are listed below:

1) International Linear Collider (ILC):

- a. Establish a high gradient, 1.3 GHz cryomodule test area at Fermilab with a high quality pulsed electron beam using an upgraded A0 photo-injector.
- b. Establish a factory with infrastructure for the assembly of prototype cryomodules using cavities produced at collaborating institutions and industries.
- c. Fabricate 1.3 GHz high gradient prototype cryomodules in collaboration with laboratories, universities and US industrial partners. Test cryomodules and other RF components as fabrication and operational experience are acquired and designs are optimized.
- d. Demonstrate 1.3 GHz cavity operation at 35 MV/m with beam currents up to 10 mA at a ½ % duty factor. Higher currents or duty factors may be explored if the need arises, but are beyond the present scope of the proposal.
- e. Develop the capability to reliably fabricate high gradient and high-Q SRF cavities in U.S. industry.

## 2) Proton Driver (PD) Low Beta ( $\beta < 1$ ) Cavity Program

- a. Fabricate test structures and cryomodules for Proton Driver applications.
- b. Establish an area for high power, 325 MHz, RF testing of  $\beta < 1$  accelerator structures in pulsed mode ( $\sim 1\%$  duty factor).
- c. Demonstrate operation at 27 MV/m with beam currents up to 8 mA at  $\frac{3}{4}\%$  duty factor. Higher currents or duty factors may be explored if the need arises, but are beyond the present scope considered in this proposal.
- d. The Proton Driver also uses  $\beta=1$ , 1.3 GHz cavities cryomodules that would be nearly identical to those for the ILC. There would be a significant overlap in ILC and PD R&D activities in this area.

## 3) CW:

- a. Fabricate the highest attainable Q-value cryomodules with emphasis on accelerator and deflecting cavities.
- b. Establish a test area with pulsed beam availability that will extend the reach of the present U.S. program in CW capabilities. This area will make use of the  $\beta=1$  pulsed test beam. Possible low current CW beams may be considered in the future (high current CW beams are available elsewhere).
- c. Demonstrate 20 MV/m CW cavity operation with Q values of  $\sim 3 \times 10^{10}$  for light source applications, with associated RF controls.

## 4) Rare Isotope Accelerator (RIA) Production Facility:

- a. Clean and cold-test individual cavities after chemical processing.
- b. Clean and assemble cavities into cavity strings, forming a sealed unit including RF couplers, beam line valves, and vacuum manifold and valves.
- c. Assemble cryomodules incorporating the cavity strings.
- d. Cold test and high power test assembled cryomodules.

## 5) Accelerator Physics and SRF R&D

- a. Construct and operate an improved photo-injector that would provide beam for the  $\beta = 1$  and CW module tests and be the centerpiece of continuing beam physics program for understanding and improving all types of facilities based on electron linacs, and the training of accelerator scientists.
- b. Begin a program of R&D on high-gradient and high-Q SRF cavity design and construction.
- c. Establish a program of SRF material research to improve cavity performance.

The proposal presented in the following sections outlines an R&D program for the next 8 years including cost and schedules (FY05-FY12). The budget has been planned with the understanding that the infrastructure, ILC and PD components and operation is managed by Fermilab. The component budget for RIA and CW areas are the responsibilities of the lead laboratories for these projects. The budget has been divided into the SMTF infrastructure part, the component parts for the four proposed areas and the operation of the facility. The operations budget includes support for training young scientists and engineers, who will be essential for the next generation of accelerators. The budget estimates are \$23M for the infrastructure, \$18M for the International Linear Collider, \$6M for Injector Upgrades, \$16M for Proton Driver, \$2M for Rare Isotope Accelerator cavity testing, \$9M for CW cavity research and finally, \$22M for operations over a 8 year period. The requested M&S funds is \$96M. Contingency has been estimated to be 10% on the operational costs and 25% on all other M&S costs for a total estimated contingency of \$20M. The total requested fund is \$116M. The estimated personnel for SMTF infrastructure is 149 FTE-years, 622 FTE-years for operations, 80 FTE-years for ILC, 30 FTE-years for the injector, 26 FTE-years for CW, 7 FTE-years for RIA, and 88 FTE-years for proton driver. The estimated FTE-years needed over all areas and operations is ~1000. The total budget includes the RIA hardware budget and FTE requested from SMTF at Fermilab. The RIA specific cost, such as the cost of cryomodels etc., is not included in the SMTF total budget.

The schedule in this proposal extends through 2012 because we expect that SMTF will be an important facility for the ILC project to proceed on the schedule as presently envisioned by ICFA. The facility will be necessary in the initial stage of the industrial production of cryomodel and associated components.

## 2. Introduction

A variety of projects are being planned in particle physics, nuclear physics, and fields of basic energy sciences such as condensed matter physics and biological physics that propose to use SRF linac technology. These projects are distributed across many of the major US laboratories funded by DOE and NSF. We propose to construct a SRF cryomodule and test facility (SMTF) in the meson area at Fermilab. A medium energy electron beam and a low energy  $H^-$  beam would permit a unique opportunity for characterization of the properties of superconducting RF cavities and for beam-related experiments. The members of the team are from a consortium of several US and international laboratories and universities.

We list several possible future projects that use RF Superconductivity.

- 1) International Linear Collider (ILC)
- 2) The Rare Isotope Accelerator (RIA) (located at Argonne or MSU)
- 3) Proton driver at Fermilab or BNL.
- 4) Upgrades (12 GeV) to Jlab electron linac, the extensions of the FEL and the proposed ELIC (Electron Light Ion Collider)
- 5) SNS (Spallation Neutron Source) upgrades to higher beam power  $\sim 4$  MW.
- 6) Fourth generation light sources at ANL, BNL, Cornell, JLAB, LBNL, and MIT using SRF linac technology for ERLs (energy recovery linacs) or FELs (free electron lasers).
- 7) Brookhaven plans to use ERLs for electrons colliding with RHIC heavy ion beams (E-RHIC) and for electron cooling of the RHIC beams.

These projects have common or similar RF systems and require development that would benefit from a coordinated effort among the laboratories. Several of the laboratories have infrastructure to carry out SRF development but have limited fabrication capabilities. The current efforts in SRF are broadly funded by USDOE HEP, Nuclear, Basic Energy Sciences and the NSF. Many of the above projects would benefit from a cryomodule test facility with beam capabilities, which is presently not available in the US. We propose such a facility and refer to it as the SMTF. It would fill the gaps in the existing SRF development capabilities.

The critical tests that groups from the above projects could perform at this facility include:

- 1) Demonstrate for ILC 1.3 GHz cavity operation at 35 MV/m with beam currents up to 10 mA at a 1/2% duty factor in four cryomodules with 8 cavities each.
- 2) Demonstrate for CW applications 20 MV/m cavity operation at  $Q$  values  $> 3E10$  and develop accelerating and deflecting cavities.
- 3) Demonstrate for the Proton Driver 1.3 GHz,  $\beta \sim 0.5-0.8$ , elliptical cavity operation at  $> 15$  MV/m at  $Q > 5E9$  and a 1% duty factor with multiple cavities being driven by one klystron.
- 4) Demonstrate for the Proton Driver and related applications high gradient operation in

- pulsed mode of 1.3 GHz and 325 MHz,  $\beta < 1$  cavities and cryomodules.
- 5) Demonstrate individual cavity resonance control with multiple cavities driven from one klystron, using fast ferrite phase shifters, at both 1.3 GHz and 325 MHz
  - 6) Demonstration of RIA cavities and cryomodules.

These demonstrations encompass research and development topics critical for the continued iteration and evolution of SRF linac systems, for the development of cost effective low to medium  $\beta$  linac sections needed for proton/ion linac, and development of lower power cost (driven by refrigeration costs) CW operation for the many upcoming light source applications and for the future ILC.

This proposal is developed in collaboration with Jlab. Jlab has submitted a SRF Accelerator Science and Technology proposal to DOE Office of Science in FY 2004. Every effort has been made, via mutual collaborative efforts between the two proponents to make the two proposals as complementary as possible. A joint document between Fermilab and JLab is being developed to address these two proposals.

Similarly KEK is also developing a Superconducting Test Facility (STF) proposal to be submitted to the funding agencies in Japan for the International Linear Collider R&D. KEK is also a collaborator on the SMTF proposal. We have developed this proposal in collaboration with DESY and KEK with the common goal of R&D and industry involvement in each region with the goals of reducing the cost and advancing the SRF technology.

Thus the SMTF goals are to:

- Design, fabricate and test SRF cryomodules and associated systems
- Provide infrastructure for cryomodule and linac systems test
- Collaborate on SRF technology development including industrial collaboration

## Proposed SMTF Plan

We propose to develop the meson east area at Fermilab into a cryomodule test area. The document is organized around the four main SRF areas: the 1.3 GHz,  $\beta=1$  ILC Cryomodule test facility, the CW test area for next-generation CW light source, and the  $\beta < 1$  test area for PD, and the RIA facility. These R&D activities will operate under a shared infrastructure of the Meson cryogenic facility, pulsed RF and modulator power sources, controls, safety and technical support.

The allocated space should be able to accommodate initially four test areas. The high gradient pulsed work and the CW activities would be located in a single 100-150 meter beam line. A second area would be large enough to accommodate the 325 MHz  $\beta < 1$  cryomodule activities. We anticipate four different communities using the facility. At the

same time these communities will have strong interactions to benefit all four areas. One community will concentrate on 1.3 GHz pulsed high gradient tests, such as needed for the ILC and Proton Driver. Another community will focus on cryomodule operation needed for present and the fourth generation light sources and other proposed applications that use high Q, CW operation. The third and fourth communities will emphasize  $\beta < 1$  activities at various RF frequencies. We envision that the regions will initially operate in two different modes. In one region, physicists would perform high power cryomodule tests as well as beam tests with a medium energy electron beam (40 - 300 MeV). This is the energy of the injector into the first cryomodule. We would also develop a beam analysis section downstream of the cryomodule. In the parallel region, tests (initially without beam) could be ongoing with low  $\beta$  demonstration cryomodules. Shielding between the two regions will be necessary for flexible operation. The details of the layout are presented in section 10.

The electron beam test area in SMTF would consist of an electron beam injector, a beam analysis region after the injector and before the cryomodules in order to measure incoming beam properties, a section of four cryomodules, which constitutes two ILC RF units (defined later), and space afterwards to evaluate the outgoing beam properties. The CW activities are located downstream of the ILC cryomodules. The existing FNPL would be an appropriate initial source. To achieve 40-300 MeV will require upgrades to the source as described in section 8. This consists of a gun and accelerating section, and is about 15 m (upgraded eventually to 25 m) in length. We estimate that 20 m of beam analysis space is needed to measure beam properties, followed by space for four 12 m cryomodules, and an additional 20 m of analysis space for the outgoing beam and a beam dump, for a total of 100-150 m.

The cryogenics plant in the meson area needs to be upgrade as described in section 10. We propose a two step approach. For the first step we make minimal modifications to the existing infrastructure and utilize what we can to supply the area quickly with about 60 Watts of refrigeration at 2K. Each TESLA Test Facility (TTF) cryomodule (eight 9-cell cavities) consumes about 36 Watts of refrigeration at 2K. The third step will requires a new refrigeration plant that can handle  $\sim 300$  Watts. Medium energy electron beams will be used for testing the cryomodules in the area and dark currents should be expected from the cavity modules, therefore the appropriate radiation shielding will be necessary.

To get started quickly we propose to initially use an eight cavity cryomodule from DESY of the type being produced for TTFII. In parallel, we would aggressively move to construct cavities and cryomodules in the US. KEK will provide cavities to be tested inside this ILC cryomodule. We note that US industry considerably lags European industry in SRF technology and our plans would help correct this situation. This is especially desirable given the large number of SRF projects in the US, and the large scale of the ILC. We also note that significant infrastructure exists at US laboratories but will also need upgrading. We plan to incorporate existing infrastructure and expertise at US labs and universities as well as US industry to build cavities, carry out bare cavity tests in vertical Dewars, perform dressed cavity horizontal tests, and assemble cavity strings and cryomodules. In addition we would build couplers and tuners and other cryomodule

components to extend the full range of expertise and technology required for the major projects envisioned.

In Phase I it is expected that ILC-Americas, Proton Driver, RIA, CW and  $\beta < 1$  interests will launch independent but collaborative activities to build cryomodule(s). Individual laboratories are assuming responsibility for major subsystems and pre-testing efforts. The proposal is that, with coordination from the ILC-Americas collaboration, Fermilab will lead the effort of fabricating and testing the ILC cryomodule. Fermilab will also lead the effort of fabricating and testing the PD cryomodules and ANL will lead the RIA cavities testing and production work. The leadership of CW cryomodule fabrication for light source applications is not yet established.

This document is organized around the four main SRF areas: ILC, CW, Proton Driver and RIA programs. Even though we present the four research concentrations separately for ease of reading, the resources and goals significantly overlap. Each area will benefit from the collective effort.

### 3. International SRF Activities

This section is a summary of the worldwide accelerator projects based on SRF together with a short description of the expertise and infrastructure developed for their success. Many of the laboratories involved in these projects are SMTF collaborators who plan to use the advances in SRF technology to launch new accelerator projects, also briefly described. SMTF activities and the test facility will play important roles in realizing future projects.

Superconducting cavities have been operating routinely in a variety of accelerators with a range of demanding applications. With the success of completed projects, niobium cavities have become an enabling technology offering upgrade paths for existing facilities, and pushing frontier accelerators for nuclear physics, high energy physics, materials and life sciences. With continued progress in the basic understanding of superconductivity, the performance of cavities has steadily improved to approach theoretical capabilities, giving rise to a large number of exciting new applications.

Superconducting linacs providing precision beams of heavy ions have consistently been one of the most successful applications. At Argonne National Lab, ATLAS has been operating for more than 25 years as a national user facility for heavy-ion nuclear and atomic physics research, logging over 100,000 beam-on-target hours of operation. Besides the pioneer accelerator at Argonne, eight heavy-ion accelerator facilities have operated or are still operating at Stony Brook, U. of Washington, Florida State U, Kansas State U., JAERI (Japan) ALPI (Italy) ANU (Australia) and the Saclay heavy ion linac. These utilized over 270 resonators made of niobium or lead-on-copper. These accelerators provide beams with mass up to 100 atomic units and energies up to 25 MeV per nucleon. New heavy-ion accelerator facilities utilizing superconducting structures are near completion at Sao Paulo (Brazil), New Delhi and Bombay. TRIUMF in Canada is upgrading ISAC with a superconducting heavy ion linac to ISAC-II facility with a final energy to 6.5 MeV/u and mass range up to 150.

At the frontier of nuclear science, CEBAF at Jefferson Lab in the USA has been one of the largest SRF installations. Superconducting cavities offer special advantages to electron accelerators for nuclear physics in the 1 to 10 GeV range: high average current, low peak current, continuous beam, and excellent beam quality. Construction finished in 1993 with installation of 380 cavities. Originally designed for 4 GeV, CEBAF achieved beam energy of 6.5 GeV in five recirculating passes with a CW beam current of 200  $\mu$ A. Over a period of a few years, CEBAF upgraded their in-line accelerating gradient from the design value of 5 MV/m to more than 7 MV/m. CEBAF operates for more than 5000 hours per year. By now they have accumulated more than 2000 cavity-years of automated operation. Plans are underway to raise CEBAF energy to 12 GeV with the installation of 10 higher gradient cryomodules, now under construction.

High-energy physics benefits from colliding beam storage rings of steadily increasing energies. Because energy loss increases as the fourth power of the beam energy (in circular machines), the electron and positron storage rings need high gradient CW

superconducting cavities for reaching high energies. The colliding beams facilities that use(d) SRF are (were) TRISTAN at KEK in Japan, LEP-II at CERN in Switzerland, and the electron-proton collider HERA at DESY in Germany, as well as high current, high luminosity machines CESR-III in the USA and KEK-B in Japan. LEP-II at CERN in Europe has been the largest SRF installation. CERN installed a total of 465 meters of SRF cavities to provide more than 3.6 GeV reaching the highest energy electron-positron collisions: 208 GeV in the Center-of-Mass before LEP-II shut down for installation of the LHC. Instead of using bulk sheet niobium cavities, CERN developed a unique approach for LEP-II: to sputter a thin film of niobium on to a copper cavity. LEP-II upgraded the in-line performance of their cavities from 6 to 7.2 MV/m by successful high-field conditioning with both pulsed and continuous RF.

With 14 TeV in the CM, the LHC at CERN will keep pace with the historical rate of energy growth for proton accelerators. Superconducting cavities and cryomodules are ready for LHC. At 400 MHz, 16 Nb-Cu cavities in 4 cryomodules will provide 16 MV per beam and will deliver about 180 kW of beam power.

Electron storage rings as x-radiation sources have enormous impact on materials and biological science. At Cornell, CHESS has been operating as a parasitic light source with CESR for two decades. After replacing the CESR copper RF system of 20 cells by a superconducting RF system with 4 cells, the beam current was increased from 300 mA to 750 mA, and accordingly the radiation flux. Cornell has transferred the technology of CESR cavities to ACCEL company in Germany which is providing turnkey systems for major storage ring light sources around the world. Such systems will be used in the Taiwan Light Source, the Canadian Light Source and the DIAMOND light source in England. BEPC in China and the Shanghai Light Source envision using SRF based on the KEK-B system. Saclay-CERN collaboration developed a 350 MHz Nb-Cu SRF system for SOLEIL in France.

A 3<sup>rd</sup> harmonic (1.5 GHz) SRF system allows bunch lengthening, decrease of charge density & increase of beam lifetime. After installation of such systems, both SLS in Switzerland and ELETTRA in Italy gained a factor of 2 on beam life-time. BESSY in Germany is preparing to install a 3<sup>rd</sup> harmonic SRF cavity.

The characteristics of x-rays produced by a synchrotron radiation (SR) source are limited by the qualities of the stored electron beams. The superconducting linac based Energy Recovery Linac (ERL) is a different approach to producing high quality electron beams. Electrons are not stored, so constraints of beam equilibrium in a storage ring are not a limit. Photo-injectors achieve bunches with emittances, shapes, and length superior in important ways to bunches in storage rings. A CW superconducting linac accelerates bunches to high energy while preserving the salient beam characteristics. After acceleration, superior high energy bunches pass through undulators to produce SR beams with unprecedented characteristics. After producing SR, the electrons in an ERL re-enter the linac, but 180° out of accelerating phase. These bunches are then decelerate and yield their energy back to the linac electromagnetic field. The energy recovered by the linac accelerates new electrons. The emerging low energy beam is deflected into a beam dump.

A Cornell/JLab collaboration has proposed an energy recovering SRF linac operating at energy of 5-7 GeV and an average current of 100 mA. To address many important accelerator physics issues of the injector and the main linac, there is a proposal for a small scale prototype ERL at 100 MeV and 100 mA. Daresbury (UK) has started construction on a prototype for its Fourth Generation Light Source (4GLS) project, a 600 MeV, 100 mA energy recovery linac driving a suite of light sources to generate radiation in the 3 - 500 eV range (IR to XUV). KEK is considering a 2.5 - 5 GeV, 100 mA ERL light source along the design of the Cornell ERL. BNL is exploring luminosity upgrades to RHIC by using high current (100 – 300 mA) electron beams from an ERL to cool the RHIC beam.

Free Electron Lasers (FELs) are sources of tunable, coherent radiation at wavelengths covering a wide range from mm to the vacuum UV and soft X-rays. SRF-driven FELs have reached unprecedented values of wavelength and average output power. The first FEL beam was demonstrated nearly two decades ago with a 50-MeV beam from the SCA at Stanford. The Jefferson Lab IR FEL has “lased” in the 1-6  $\mu\text{m}$  wavelength range and reached average output power of 10 kW, the highest CW average power ever to be achieved. JLab also demonstrated energy recovery with more than 99.8% efficiency. Nearly one MW beam power was energy recovered. This is an important milestone toward high beam power Energy Recovery Linacs of the future. Other CW FEL projects underway are at JAERI in Japan and at Darmstadt in Germany and ELBE at Rossendorf.

At ultra short wavelengths, less than 100 nm, mirrors are not available for FELs which must be based on the SASE principle, Self-Amplified-Spontaneous-Emission. The Tesla Test Facility (TTF) at DESY has a dual purpose. (1) To demonstrate a high gradient SRF linac to prepare the superconducting technology for the International Linear Collider and (2) To advance the science of SASE while providing UV to x-ray beams to a user facility. TTF has lased over a wavelength range from 80 nm to 180 nm, corresponding to a beam energy between 181 and 272 MeV, to demonstrate SASE saturation at the wavelength of 98 nm. An upgrade to one GeV is underway. The German government has agreed to supply partial funding for a European X-ray FEL at DESY with the capability of reaching the one  $\text{\AA}$  wavelength range. Other European labs are soliciting their ministries for the remaining financing.

There are several studies in progress for future X-ray FELs. Many concepts are based on an evolution of high gradient technology for the linear collider. Lawrence Berkeley National Lab is developing the Laser Based Ultra-Fast X-Ray Facility (LUX) to produce femtosecond x-ray pulses with high flux, and repetition rate matched to the requirements of structural dynamics experiments. The 2.5 - 3 GeV machine is based on a 1300 MHz SRF 4-pass recirculating linac for acceleration of electrons (average current 10uA) produced by a high-brightness photocathode RF gun, at a bunch repetition rate of approximately 10 kHz. MIT is studying an X-ray laser facility to span a broad range of wavelengths from the ultra-violet to the hard X-ray region using fundamental and third harmonic, generation. The accelerator configuration would include a staged superconducting electron linac from 1 to 4 GeV, multiple undulators and beam lines. BESSY in Berlin proposes a single-pass 1.5 – 2.2 GeV FEL for wavelengths between 63 and 1.2 nm.

Stimulated by the success of SRF technology around the world, the Spallation Neutron Source under construction at Oak Ridge switched to SRF in 2000. Neutron scattering is an important tool for material science, chemistry and life science. The SNS at Oak Ridge National Lab will be an advanced pulsed spallation source with 1.4 MW of beam power at the target, upgradeable to 5 MW. This would correspond to the average flux of the highest flux reactor at Grenoble. From 200 MeV to 1000 MeV, 800 MHz SRF cavities will drive the SNS linac. As one of the partner labs, JLab is responsible for linac design and construction. There will be a total of 81 (one meter-long) cavities operating at 804 MHz. Eleven medium-beta (0.64) cryomodules have three cavities each and 12 high-beta (0.81) cryomodules will have four cavities each. Performance above design specifications has been achieved for the bare cavities and cryomodules.

The highest priority for a major new facility in the Long Range Plan of the US Nuclear Science Advisory Committee is the Rare Isotope Accelerator, RIA. There will be two major sections to RIA, a superconducting multi-ion multi charge-state driver linac spanning nearly the entire range of masses from protons to uranium and particle velocities,  $0.02 < \beta < 0.84$ , and a superconducting post accelerator of efficient acceleration and transmission of multi charge-state rare isotopes. In Europe, SPES and EURISOL are RIA type facilities also under study.

Future spallation neutron sources, neutrino beam lines, neutrino factories and muon colliders place a heavy emphasis on developments in high intensity proton linacs and relevant superconducting accelerator technologies. Fermilab, CERN and Brookhaven are studying high intensity proton linacs for multi purposes. As discussed in this proposal, the Fermilab 8 GeV superconducting linac could supply the Main Injector to produce super beams for neutrinos and intense beams for anti-proton production, or the linac could directly produce muons and spallation neutrons. CERN is studying a multi-purpose SRF proton linac (SPL) for a super neutrino beam, a possible neutrino factory, as well as to upgrade the injector chain for the LHC, and to produce heavy ion radioactive beams for nuclear physics. Using SNS cavity technology at twice the frequency, a 1.2-GeV SRF linac for a 1-MW AGS upgrade at BNL aims to increase the AGS beam power by a factor of 10 in order to produce intense neutrino beams and for other applications.

For the future high intensity proton accelerators could play a major role in Accelerator Based Transmutation of Waste (ATW). Spallation neutrons transmute long-lived actinide isotopes and fission products to stable isotopes, or to isotopes that decay to stable products over 100 years. This approach can lessen the technical problems of storing long-lived high level radioactive waste. In an optimistic design, a single accelerator can burn the waste from ten 1 GW reactors, while providing enough power to run itself. A European consortium is studying XADS, a 10 mA CW, 600 MeV (tunable) proton linac based on SRF technology developed in earlier national projects (ASH, IPHI, TRASCO, ESS, and CONCERT) JPARK in Japan is developing a 200 MeV SC section to upgrade energy for future ADS applications. The Korean Multi-purpose Accelerator Complex KOMAC at KAERI is studying a one GeV 20 mA linac for waste transmutation, medical therapy and industrial applications. There is a similar Indian ADS program at Center for Accelerator Technology (CAT) in Indore.

Extensive SRF infrastructure exists worldwide for cavity fabrication, surface treatment, clean assembly, cold testing, cavity string assembly, and final cryomodule assembly before accelerator installation. Substantial infrastructure exists in US Laboratories and will be used for the module activities of SMTF.

In general, cavity production facilities include eddy current scanning machines for material inspection, hydraulic presses for deep drawing cavity half-cells, digital control milling machines for precise trim machining, and large electron beam welders for finished structures. Final tuning and inspection systems consist of automated tuning machines and co-ordinate measuring machines. Cleaning facilities include open and closed cavity etching systems, electropolishing set-ups, high purity dust free water systems, and high pressure (100 atmospheres) water rinsing. UHV furnaces purify cavities at 1350 C under high vacuum. Test setups include radiation shielded pits and bunkers, cryostats, and cryostat inserts, multi-hundred watt CW RF power sources and MW class pulsed klystrons for high power operation and high pulsed power processing. Test systems are supported by refrigeration to 2 K. There are large Class 10 - 100 clean rooms for cavity and cavity-string assembly. Cryomodule assembly areas are equipped with major survey, support and alignment tools.

Major facilities for all the necessary operations are available at DESY and Jefferson Lab. CERN, INFN, Saclay, KEK, Cornell, Los Alamos, ANL, and Fermilab have comprehensive facilities that cover many (but not all) of the stages. Several industries around the world have installed significant capability to cover various stages. Most of these industries are in Europe and Japan.

These facilities have been used to build cavities and cryomodules for TRISTAN, HERA, CEBAF LEP-II, CESR, KEK-B, FELs, ATLAS, SNS and the TESLA TEST FACILITY. Major facilities for low velocity accelerators are available at INFN, ANL, Michigan State University, and Los Alamos National Lab. SMTF plans to use the facilities in the US to fabricate cryomodules at Fermilab in conjunction with developing the capability of industry.

## 4. ILC Test Facilities

This section describes the ILC program that will be based at FNAL and the associated facilities at SMTF. In broad terms, the goal of this program is to build at least four ILC cryomodules (8 cavities per cryomodule) in the next several years that meet performance requirements. This work would proceed in phases as outlined below and is illustrated in Figure 4.1. The ILC and proton driver R&D associated with the  $\beta=1$  cryomodules have nearly complete overlap and therefore we describe only the  $\beta<1$  R&D in the proton driver section. Fermilab relies on ILC activities to address R&D issues associated with the  $\beta=1$  cryomodules.

Prior to the formal start of SMTF activities in FY06, the SMTF-ILC collaborators are beginning the fabrication of four ILC cavities in the US. Work is beginning with KEK in defining the 4 cavities expected to be delivered to Fermilab in FY06. Also, construction would begin on a horizontal test stand, which is a cryostat that allows a single fully dressed cavity to be operated with pulsed, high power rf. This test stand would be located in the Meson East area and the construction of the associated infrastructure would begin in FY05 as well. Finally, a capture cavity that was recently acquired for the A0 photo-injector would be commissioned to a gradient of 25 MV/m.

Phase One, FY06-FY08. The goal during this period would be to fabricate two cryomodules. One of these, the ILC-cryomodule, would contain cavities made in the US and Japan, and would be assembled at FNAL. The other, the TESLA-cryomodule, would be obtained from the DESY collaboration although the degree to which the cavities and cryomodule would be assembled when received is yet to be determined. Of these two cryomodules, at least one would be tested with beam in early FY07. For this purpose, the A0 photo-injector would be moved to the SMTF area. Its initial configuration (Injector-A) would consist of a gun and two capture cavities, which would allow for basic accelerator performance testing (the Injector-B configuration in Figure 1 refers to the addition of third-harmonic cavities for a beam dynamics program that has been proposed with this injector - see the 'Accelerator Physics and SRF R&D' section).

Phase Two, FY08-09. The second cryomodule would be installed and the pair would be powered by a single 10 MW klystron. Subsequent iterations to the cavities are envisioned to improve the performance of these cryomodules. Construction would start on two additional cryomodules.

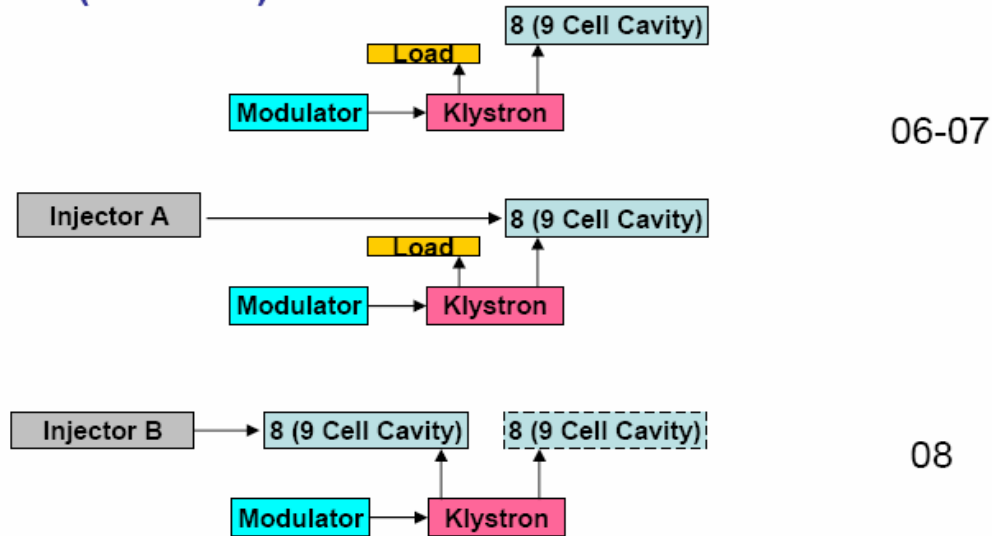
Phase Three FY09-11. Eventually four cryomodules, three built in the U.S., would be installed and used to accelerate ILC-like beams. The energy upgrade of the injector will likely occur in FY11-12.

A major objective of the US university/laboratory/industrial partnership is to learn how to reliably fabricate high quality ILC cavities and assemble them into cryomodules. This process would utilize the expertise within the international ILC collaboration and would

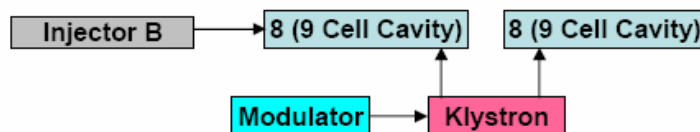
be an important first step towards industrialization of cryomodule production as this knowledge can then be efficiently transferred to large-scale manufacturers. This process would be likely be necessary in all three regions of the world that are collaborating on the ILC to produce the large quantity 2500 (500 GeV) of cryomodules that are required.

## Phases of ILC Test Facility

### Phase 1 (FY06-08)



### Phase 2 (08-09)



### Phase 3 (FY09-...)

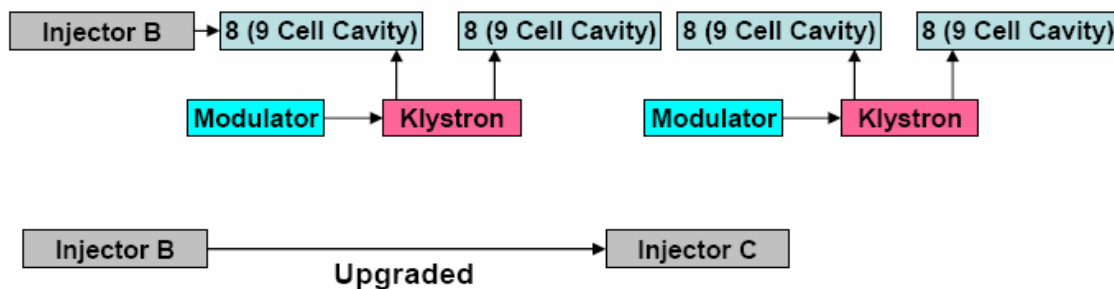


Figure 4.1 Phases of the ILC Test Facility

### **Fermilab Activities in FY06-FY08:**

Activities at Fermilab in FY06-FY08 would include testing one cryomodule with beam and upgrading the photoinjector. The first tests of dressed cavities (i.e., with He vessels and couplers) would occur in the horizontal test stand in FY06: the cavities received from KEK would likely be tested first. These tests require a 2K helium supply, RF power for a single cavity (up to 500 kW), and a low level RF (LLRF) drive system.

During FY06, FNAL would prepare to receive dressed cavities built offsite as described below. This would require completing the infrastructure at Fermilab so that the ILC-cryomodule could be fully assembled. The infrastructure needed to assemble a string of cavities, primarily the class 10 clean room, should be ready for use in MP9 early in 2006. The area where the string is assembled (300 mm support pipe, super-insulation, etc.) into the "cold mass," the materials to build the cold mass and the infrastructure for inserting the cold mass into the vacuum vessel would be ready as well.

The cryogenic plant for removing the expected heat load from one cryomodule would be finished in FY06. The RF system, including the klystron, modulator, waveguides, and controls, would also be ready for use by the end of FY06.

A significant ramp-up by US industry would be required to produce processed cavities (i.e., ones that been etched, baked and high pressure rinsed to allow high field operation). This would take a few years and a substantial investment since no US company is currently capable of producing such cavities. In particular, considerable time and cost would be required to deal with the complex environmental issues associated with the chemical enchants that are required. Industry would be used to assemble the cavities from stamped half-cells. This possibility is being pursued as are discussions with JLab and Cornell on how to exploit their capabilities in this area. If it becomes apparent that four cavities cannot be fabricated in a timely manner (~18 months), they would be purchased from ACCEL, which is a German company that supplies most of DESY's 'bare' cavities (i.e., ones that are not processed).

After eight cavities have been acquired (nominally four from KEK and four from U.S. manufacturers) and assembled in a string, experience from DESY indicates that the assembly into a cryomodule would require 3-4 months (with experience, the process should take only 3-4 weeks). The goal would be to have a complete eight-cavity cryomodule that is ready for testing by mid-FY07. In parallel, FNAL would be prepared to receive a cryomodule from the TESLA Collaboration on the same time scale.

The A0 photo injector can be moved to the meson area for use once the first cryomodule is assembled and it is ready to be energized. It is assumed that this might be late FY07. By this time, the injector with two capture cavities will be installed and ready for testing. Cryomodule beam tests will be interspersed with the photo injector planned upgrades. The first ILC-cryomodule would be built on a "best effort" basis and gradients in the 20-25 MV/m would be the initial goal. Under-performing cavities and components would be replaced or upgraded as they become available. The TESLA-cryomodule would be

expected to arrive in FY07 and the "best" cryomodule would be tested with beam. How the TESLA cryomodule would be shipped to Fermilab is still being discussed as there is a concern that shipping a fully assembled cryomodule might damage its delicate components. Fermilab should have the ability by that time to convert a cavity string into a full cryomodule, so perhaps shipping the cavity string separately from the other components would be more prudent.

#### **Activities at Other Sites in FY06-FY08**

In early FY06, the electro-polishing capabilities at JLab would be commissioned using cavities provided by DESY. In addition, JLab would upgrade its testing infrastructure to allow vertical testing of 1.3 GHz cavities. JLab would also prepare to receive vertically tested cavities from Industry/Cornell and dress, test, and ship them to Fermilab for string assembly. It is possible that the KEK cavities would be dressed at JLab and then shipped to Fermilab, the specifics are still under discussion with KEK, JLab, and Cornell. Cornell would need to make minor improvements to its infrastructure in order to test new cavities.

Argonne and Fermilab will complete a chemical processing facility for the third-harmonic photo-injector cavities in FY05 and begin adaptation for processing TESLA cavities. After that, the facility will be upgraded to include electro-polishing.

### **4a. RF Power for the ILC Test Facility**

The operating parameters and layout of the RF units for the ILC linacs is in the process of being defined for both 500 GeV operations and a future upgrade to 1 TeV operation. The choice of operating gradient is tending towards 35 MV/m in both cases (to be compared to 23.4 MV/m in the TESLA 500 GeV design and 35 MV/m in the TESLA 800 GeV design). The power sources currently being developed can provide 10 MW of RF power so it is natural to define an RF unit as the number of cavities powered by such a source (i.e., one modulator and one klystron). Given the state of cryomodule development and the desire to have some overhead in choosing the ILC beam current, an ILC RF unit has been defined for test purposes at SMTF as two cryomodules with eight TESLA-like (9 cell) cavities each. Assuming 6% RF transport losses, each cavity in the RF unit could be powered up to 530 kW with a 10% overhead. At 35 MV/m, a 15 mA beam could be accelerated, which is about 15% more current than in the TESLA 800 GeV design. The present concept for the ILC cryomodule is based on the TESLA Test Facility (TTF) design, which contains eight nine-cell cavities. It may be cost effective for the ILC to have 12 nine-cell cavities per cryomodule as was proposed in the TESLA Technical Design Report.

In the past 24 cavities have been assumed for a TESLA high gradient RF unit. This configuration is also possible at SMTF with three 8 cavity modules and a beam current of 10 mA. Coupler power requirement and injector beam requirements are consequently less. The specifications in this proposal are based on a 10 mA beam and a ½% duty factor. These requirements will be reviewed as ILC parameters evolve.

The power system at the facility will need to accommodate two complete 1.3 GHz RF

units (each unit contains two eight-cavity cryomodules). Each RF unit is nominally powered by one 10 MW klystron and modulator. These klystrons will likely be purchased from one or more of the three vendors (Thales, CPI and Toshiba) that DESY has contracted to develop such tubes. These vendors have produced prototype 10 MW tubes but none has yet performed at the level required for the SMTF. The development of these tubes by DESY will undoubtedly continue, especially as they will be used for the DESY-based XFEL project as well. In the meantime, FNAL owns commercial 5 MW tubes that could be used instead (one per cryomodule). Specifically, they have a Thales 2104 klystron that is a spare for the A0 injector and they recently acquired six Thales 2095 tubes that were originally at LANL (5 were in operation there). It is anticipated that, with coordination from the ILC-Americas collaboration, SLAC will lead the ILC RF power source efforts, and source development and testing will be carried out there as well.

Two modulators for SMTF are currently under construction at Fermilab. These are designed specifically to power any of the following: the 10 MW 1.3 GHz multi-beam klystrons from Thales, CPI, or Toshiba; the 325 MHz JPARC/Toshiba klystron planned for the  $\beta < 1$  linac, or the commercial 5 MW, 1.3 GHz klystrons. The modulators can be reconfigured to support pulse widths of 1.5 msec for ILC and 3 msec or 4.5 msec for the Proton Driver. A few types of klystrons and modulators will be needed for the SMTF. We assume that modulators include pulse transformers when necessary.

The proton driver would like to use a  $\beta = 1$  cryomodule as a test bed for the fast ferrite phase shifters used to provide individual phase and amplitude control for individual cavities. These tests will take advantage of the beam loading available at SMTF as well as the Lorentz detuning from the high cavity gradients to perform a full system test. The ferrite tuners are also of interest for ILC to minimize the RF and cryogenic power dissipation.

The modulator and the klystron needed for the ILC test facility is described below. The 5 MWatt and 10 MWatt multibeam klystron will be acquired from industry. The modulators will be built by a collaboration between SLAC and Fermilab with components acquired from industries. The efficiency of the modulator is assumed to be about 67%. Therefore a 10 MW klystron requires a roughly 15 MW modulator. We plan to build two types of modulators. The RF power requirements for the ILC modules at each phase are:

- Phase 1- one 15 MW modulator (B1), one 5 MW klystron
- Phase 2- one 15 MW modulator (B1), one 10 MW klystron
- Phase 3- two 15 MW modulators (one new B3), two 10 MW klystrons (one new)

A variety of different prototypes of both klystrons and modulators should be fabricated and tested as part of the RF power development program. Several klystrons and modulators exist or are in the process of being fabrication in FY05. We will assume the following plan for the proposed phases for cost and resource estimates for FY06 and beyond:

#### Phase I

- Complete fabrication of one 15 MW modulator (B1)

#### Phase 2

- Build one 15 MW modulator (development or B3)
- Procure one 10 MW klystron & one spare

#### Phase 3

- Build one 15 MW modulator (B4)

In addition to modulators and klystrons, other klystron and RF ancillary equipment is needed. This ancillary equipment includes:

- Klystron auxiliaries ( shielding, solenoid, solenoid power supply, filament supply, vacuum pump power supply)
- Waveguide, splitters, directional couplers, circulators, loads (This is the equipment that takes the RF power from the klystron to the input couplers of the cavity.)
- RF system controls-interlocks
- Low level RF system (LLRF) including Piezo
- Fast Phase Shifter and its control

The LLRF controls-interlocks, and Fast Phase Shifters are all systems that will be undergoing development so it is expected that more than the minimum necessary will be developed, built and operated.

#### ILC Test Facility RF Systems Table

System	Phase	Cavity	Klystron nominal power	Klystron status	Modulator	Modulator status
One Module	1,	8 cavity module	Thales TH2104C 5 MW	exists\spare	15 MW “Big”	Under fab/parts procure
2 Cryo-modules	2	2, 8 cavity Cryomodule	10 MWatts	New	15 MW “Big”	New
4 Cryo-modules	3	4, 8 Cavity Cryomodule	10 MWatts	New	15 MW “Big”	New
spare			Thales, Thompson TH 2095A ~5 MW	6 units mod anode		

## 4b. High Gradient SRF Cavity R&D

Improved understanding of gradient-limiting mechanisms, together with technology advances through world-wide R&D are responsible for the steady increases in performance in the last decade. Gradients of 35 - 40 MV/m at Q values of  $10^{10}$  are now achieved in one-meter long superconducting structures suitable for the 500 GeV International Linear Collider.

One goal of future R&D programs is to push gradients and Q values even higher for TeV energies, gradient overhead, or cost savings. But above 40 MV/m the surface magnetic field approaches the fundamental limit at which superconductivity breaks down. One way to circumvent this limit is to modify the cavity shape to reduce the ratio of the peak magnetic field to accelerating field.

About two years ago, Cornell introduced a re-entrant shape which lowers the surface magnetic field by 10%. JLab has also introduced the Low Loss (LL) shape with similar peak magnetic field reduction. Although field emission is aggravated by the higher electric field, it does not present a “brick wall” limit because of the success of high pressure rinsing in eliminating field emitters. The re-entrant shape has the same beam aperture as the TESLA shape, which is important for maintaining favorable beam-cavity interaction features. The LL shape has a smaller aperture. HOM spectra studies as well as Lorentz force detuning studies are in progress at FNAL on both shapes.

A 7-cell LL cavity at JLab reached  $E_{acc} = 39$  MV/m at a Q value of  $5 \times 10^9$ . The first re-entrant single cell cavity fabricated at Cornell reached a world record accelerating field of 46 MV/m at a Q value of  $10^{10}$ . Both shapes are worthy of further exploration, as well as development of other shapes.

In phase I of the SMTF program, we propose to fabricate a 9-cell re-entrant cavity. KEK is planning to fabricate 9-cell LL cavities. A comparison of the maximum gradients reached with these structures will guide us to assess whether the basic TESLA design can be improved. If the result is positive, in Phase II we will fabricate four 9-cell cavities and aim to put these in cryomodules.

## 4c. Accelerator Physics Studies for the $\beta = 1$ modules

The beam parameters listed below are the maximum values desired at SMTF based on the possible ILC operating parameters (although a beam current as high as 15 mA would allow operation similar to that in the TESLA 800 GeV design, only 10 mA may be possible with the present injector). These parameters would serve as guidelines when considering radiation shielding, beam dumps, cryogenic cooling and RF power. Operation with ILC-like parameters is demanding with respect to radiation shielding and cryogenic cooling, and if necessary, the initial pulse rate may be lowered by a factor of 10 or more to ease the requirements. These parameters may change as ILC design progresses.

RF Pulse Length	msec	1.5
Pulse Rate	Hz	5
Beam Pulse Length	msec	1.0
Beam Current	mA	15
Electrons per Bunch		2e10
Bunch Spacing	ns	337

To study basic cavity performance during beam operation, the injector at SMTF should provide bunch trains comparable to those expected in the ILC. Addition requirements in this regard are:

- Bunch Charge: up to 2e10 electrons
- Bunch Length: as low as 300 microns rms (typically 1 mm RMS).
- Bunch Spacing: nominally 337 ns with option of halving this.
- Bunch Energy Stability: < 1% rms average
- Current Stability: < 5% rms, (preferably less).
- Number of Bunches: up to 2820.
- Pulse rep rate = up to 5 Hz

### Experimental Program

Outlined below are some of the ILC studies envisioned at SMTF, many of which require beam capability.

- Determine the maximum operating gradient of each cavity and its limitations.
- Evaluate the gradient spread among cavities and its operational implications.
- Measure dark currents, cryogenic load, dark current propagation, and radiation levels.
- Measure alignment of the quadrupole, cavities and BPM in-situ using conventional techniques (e.g., wire or optical systems).
- Measure vibration spectra of the cryomodule components, especially the quadrupole magnet.
- Measure system trip rates and recovery times to assess availability.
- Develop LLRF exception handling software to automate operation and reduce downtime.
- Evaluate failures with long recovery times: vacuum, tuners, piezo controllers, and couplers.
- Measure beam energy to provide an independent and accurate measurement of the accelerator gradient (rf based techniques are not as accurate).
- Characterize long-range wake-field by measuring frequency spectra of bunch positions downstream of the cryomodule. Search for high Q cavity dipole modes that could cause beam break-up in the ILC.
- Demonstrate that a < 0.1% bunch-to-bunch energy spread can be achieved in a 1 msec long bunch train.
- Measure the beam kicks caused by the fundamental mode fields to determine the impact on transverse beam motion in the ILC.

Assess ability to center the beam based on the HOM dipole signals.

## 5. Proton Drive Test Facility

The Proton Driver is an 8 GeV proton linac. The last 85% of the linac (1 GeV to 8 GeV) is comprised of  $\beta=1$  TESLA modules and will benefit from the ILC program. The synergy between ILC R&D and Proton Driver is further reinforced by the almost complete overlap of an ILC module test bed and what will be needed for many aspects of Proton Driver R&D. The proton driver will need 288 TESLA cavities in 36 cryomodules, as well as 96 low beta elliptical cavities in 12 cryomodules, all at 1.3 GHz. Two main uses are foreseen for the  $\beta < 1$  test area: pulsed-mode front end linac for the Proton Driver, and a possible production test facility for RIA cavities and cryomodules.

The initial RF systems will support pulsed mode operation at 325 MHz (one quarter of the ILC's 1300 MHz) and extend the TESLA-style RF fan out from one large Klystron to a large number of cavities. This will support development of a family of "ILC-compatible"  $\beta < 1$  superconducting cavities to be developed by members of the SMTF collaboration. These include single, double, and potentially triple spoke SRF cavity resonators. At higher beta, the Proton Driver will also use cryomodules with 1300 MHz elliptical cavities that will be tested in the 1300 MHz test area.

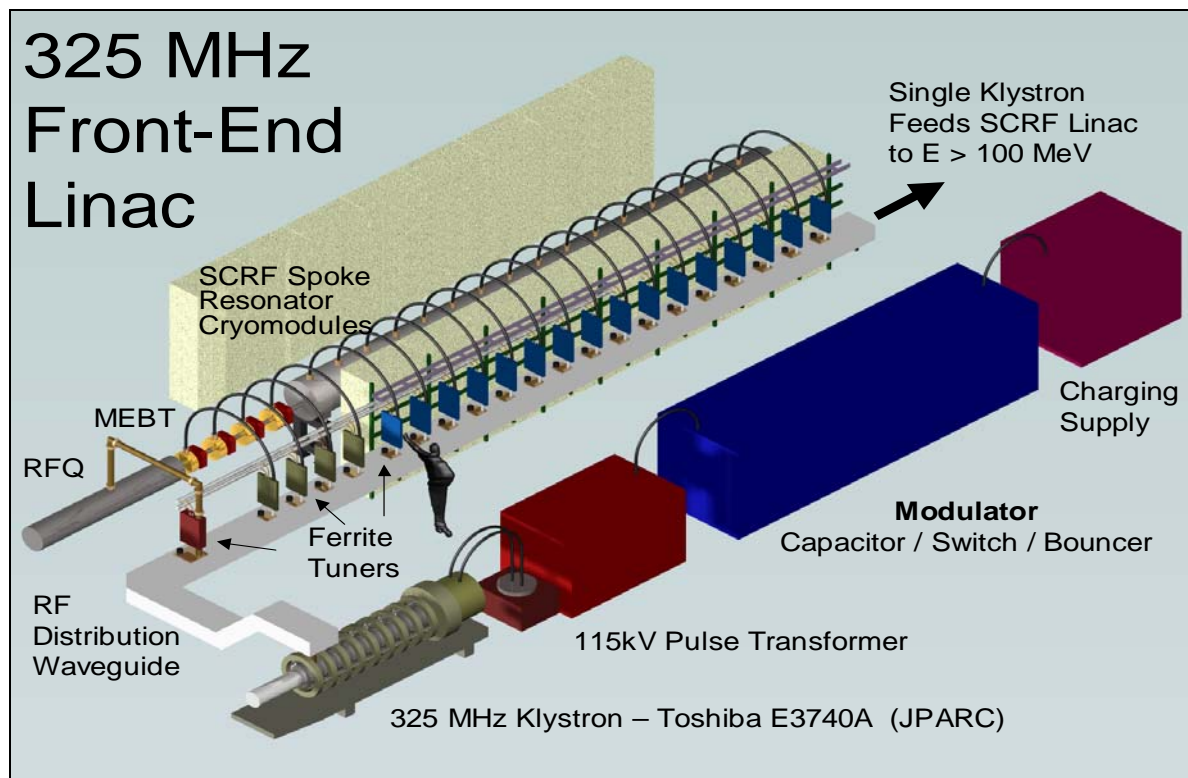


Fig. 5.1 - Beta <1 test area. The entire front-end linac is driven by a single 325 MHz klystron. Although the single klystron should be capable of driving the entire front end linac up to energy of ~100 MeV, the beam energy will be limited to ~30 MeV by the length of beam line enclosure available.

**Beam Tests.** A second phase of operation would add an H<sup>-</sup> source, and RFQ, and Medium Energy Beam Transport (MEBT) operating from the same pulsed Klystron that operates the SRF cryomodules. This would provide a beam-based test bed for LLRF and resonance control when driving low-beta ion beams with multiple cavities driven from a single Klystron. Emittance measurements, chopping, and laser stripping experiments will be possible.

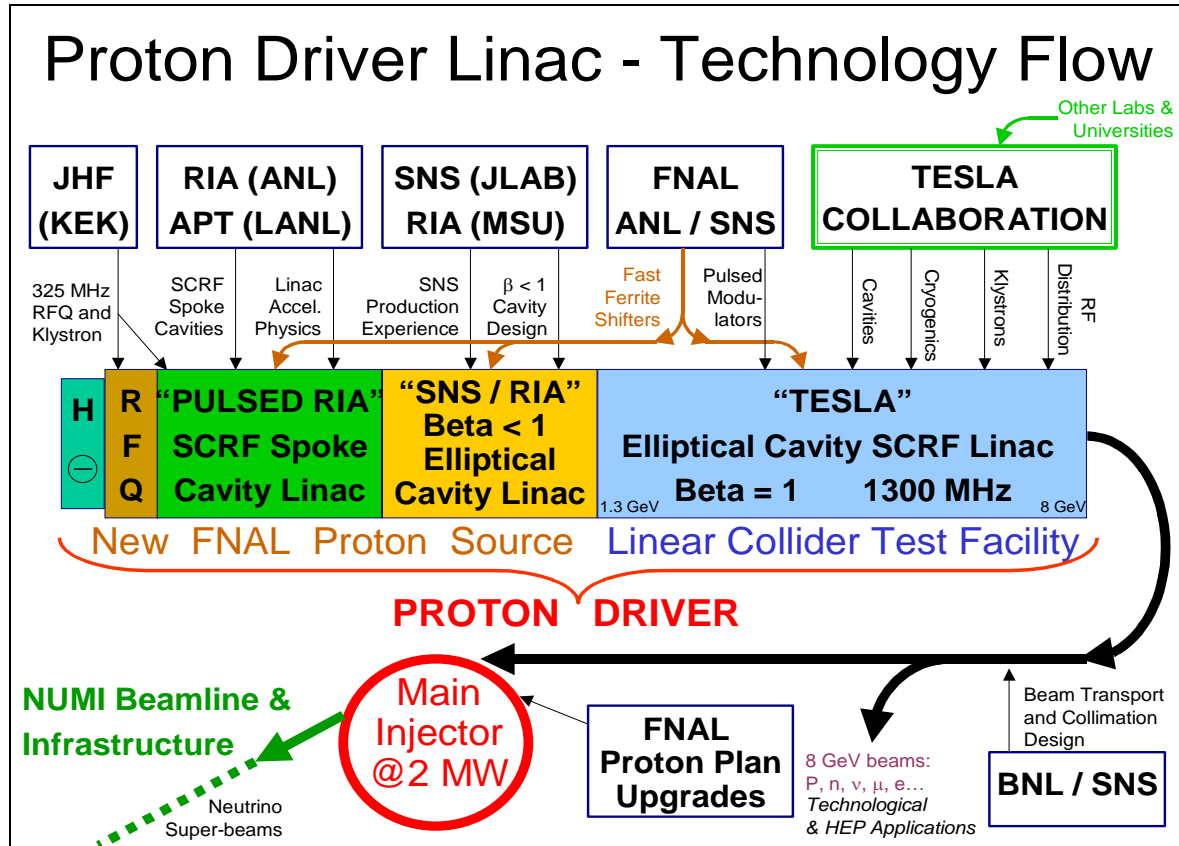


Fig. 5.2 – Evolution of technology to be tested in SMTF beta< 1 linac. The beta<1 test area would support a 325 MHz front end linac patterned on the JHF/JPARC front end, then use SRF spoke resonators patterned on the RIA cavities. The 1300 MHz test area would support beta<1 elliptical cavities and cryomodules, as well as beta=1 section patterned on the ILC main linac.

A key new technology is the demonstration of fast high-power phase shifters for SRF resonance control of individual cavities while driving a large number of cavities from a single large Klystron.

## 5a. 325 MHz Pulsed RF Systems for $\beta < 1$ Test Area

A single 3MW Klystron (the Toshiba E740A currently in production for JPARC) will provide pulsed RF power for the 325 MHz beta<1 linac. See fig.5.

The RF systems would be designed to support both the initial and upgrade beam pulse parameters for the Proton Driver. Initial operation would support beam pulses of (8.3 mA x 3 msec x 2.5 Hz), with an upgrade scenario requiring (25 mA x 1 msec x

10 Hz). Two modulators are currently under construction which can be reconfigured to support either of these pulse parameters.

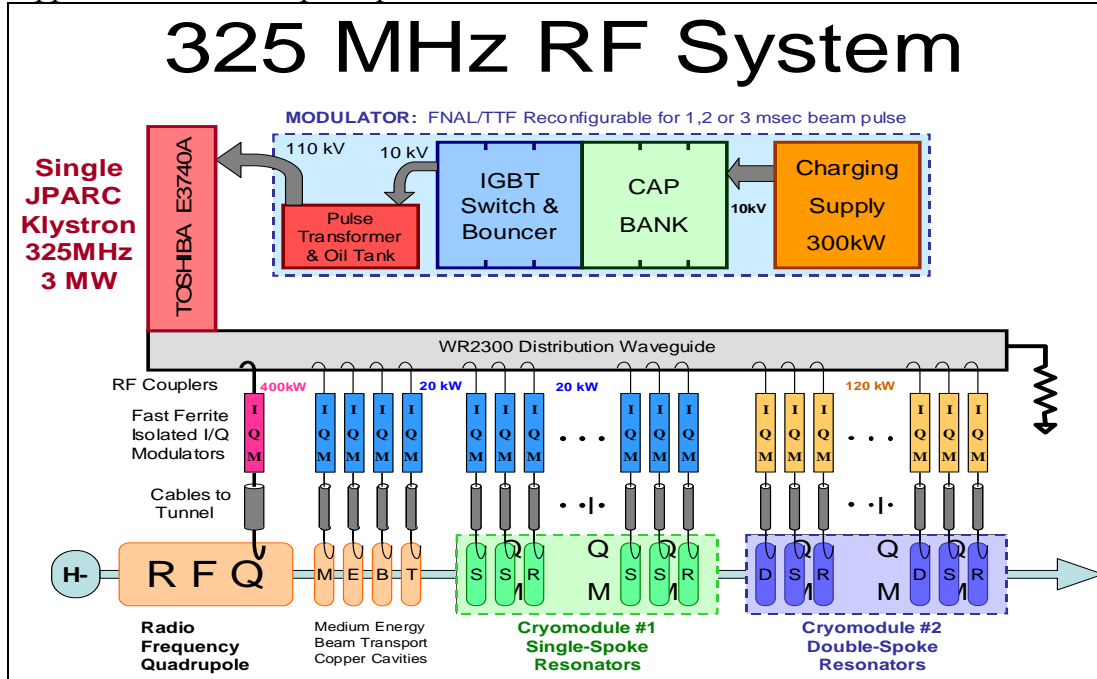


Fig. 5.3 - The RF distribution system for the 325 MHz  $\beta < 1$  pulsed SRF linac. In a TESLA-like scheme, directional couplers are used to split off power for each cavity from a long waveguide running parallel to the linac. Individual resonance control for each cavity is provided by fast tuners using magnetically biased YIG ferrite to provide individual phase and amplitude control for each cavity.

## 5b. Program sequence for the 325 MHz Pulsed Linac $\beta < 1$ Test Area

- 1) Modulator construction (already underway).
- 2) Order the 325 MHz Klystron, for delivery in FY06
- 3) In parallel, construct and begin cold tests of the RF fan out waveguide and directional coupler, to understand cross talk between couplers and related issues.
- 4) Continue development of the fast-ferrite tuner modules, with the goal of having functional prototypes at each required power level by the end of FY05.
- 5) Begin prototyping of 325 MHz cavities in various beta ranges by members of the SMTF collaboration.
- 6) Funds permitting begin procurement of the H-/RFQ front end.
- 7) Continued development and simulation of LLRF hardware and control algorithms using the ferrite tuners.
- 8) Integrated system test of the front-end linac, 325 MHz Klystron, RF distribution, ferrite tuners and LLRF control.

## 6. CW Test Facility

Superconducting RF structures operated in cw mode have advantages in providing high gradients, extremely stable RF fields, inherently small perturbative effects on the beam, and with RF power requirements considerably less than equivalent normal conducting structures. Taking advantage of advances made in superconducting RF technology in recent years, several proposals have been developed for a variety of applications of cw scrf, including an upgrade to the existing CEBAF linacs, the Rare Isotope Accelerator (RIA) (discussed in the  $\beta < 1$  section), storage-ring synchrotron radiation sources, free electron lasers, energy recovery linacs (ERL's), recirculating linacs, and beam conditioning devices such as harmonic cavities for manipulation of longitudinal phase space, and transverse deflecting cavities.

The high quality factor of superconducting structures (monopole mode  $Q_0 \sim 10^{10}$ ) results in a very long filling time of 2.4 s for unloaded 1.3 GHz structures, and very small intrinsic bandwidth ( $\approx$  Hz) for stable operation. Overcoupling the cavity to the RF power input port reduces the quality factor to a low external Q ( $Q_{\text{ext}}$ ) and decreases the filling time, but requires additional RF power to overcome reflections introduced at the coupler. In some applications the beam loading requirements provide a strong reason to lower the Q of the cavity resonance such that input conditions closer approximate a match to the beam loading. But for many applications where the system is not heavily beam loaded, significant overcoupling has a direct consequence in increased RF power costs. In such cases then, the coupling and the filling time are limited primarily by the ability to provide feedback of the system against field fluctuations induced by microphonics. For example, a 50 Hz cavity/feed system bandwidth results in an external quality factor  $Q_{\text{ext}}$  of  $2.6 \times 10^7$  for 1.3 GHz cavities, and the cavity filling time is then several milliseconds. Typically, power is applied to pulsed standing wave cavities for about three time constants before the beam enters the structure, to allow time for energy to build up in the cavity so that the required field can be developed. The applications of interest discussed here require bunch rates significantly exceeding the capabilities of a system with 1-10 ms time constant, and the superconducting linac must be operated in continuous wave (cw) mode. The resultant power dissipation due to RF currents on the cavity inner surfaces increases significantly over the pulsed design parameters, for example a TESLA accelerating cavity operating at 20 MV/m cw dissipates approximately 40 W at liquid helium temperature, compared with  $\sim 1$  W for the nominal pulsed operating mode (at about 1% duty factor). Operating in cw mode at a gradient of up to 20 MV/m, or with equivalent surface currents in deflecting (dipole mode) cavities, requires development and testing of systems to accommodate the large thermal load.

Application of cw SRF in facilities such as listed above drives advances in a broad range of accelerator communities, including storage-ring synchrotron light facilities, free-electron lasers (FELs), electron-ion colliders, and nuclear physics facilities. Dedicated research and development in cw superconducting structures offers significant potential improvements and capabilities for these facilities and opens up new possibilities for the science performed with these instruments.

Several RF structures are being developed for cw applications, at different frequencies and with different parameters, but with similar and some key overlapping

issues to be addressed. A number of facilities are currently operational and active in research and development of cw SRF for application in specific projects for light sources and nuclear physics facilities, and a number are in the proposal stage. Existing experimental capabilities include facilities at Cornell, BNL, and TJNAF JLab. R&D interests in application of cw SRF include:

- Demonstrate high gradients in TM<sub>010</sub> mode cw operations ~ 20 MV/m
- Demonstrate high transverse deflecting fields ~ 5 MV/m in TM<sub>110</sub> mode (5 MV transverse kick for 1 m of RF structure)
- Demonstrate high Q values in cw operations. One goal, for the TM<sub>010</sub> mode, is  $Q_o > 3 \times 10^{10}$
- Demonstrate high external Q values at operating gradients of ~20 MV/m, with a goal of  $Q_{ext} > 1 \times 10^7$  for the TM<sub>010</sub> mode in low beam loading applications
- Demonstrate high stability and control of microphonics, with a goal of phase error  $< 0.1^\circ$  and amplitude error  $< 10^{-4}$
- Demonstrate wakefield suppression and stable operations with realistic beam parameters (strongly dependent on application)

## 6a. Applications for cw SRF in accelerator-based facilities

Recirculating linacs and ERLs, driven by cw SRF linacs, are proposed accelerator-based x-ray sources that allow high peak and average brilliance, high temporal and spatial coherence, and ultra short light pulses covering wavelengths from infra-red to x-rays, depending on the beam energy. Using stable beams from a cw SRF linac allows utilization of the very low 6-dimensional electron beam emittance produced in high-brightness electron sources – a significant advantage over storage ring beam quality which is limited by stochastic effects (quantum emission, intra-beam scattering, radiation damping).

ERLs also allow high average photon flux by using very high beam power (high bunch rate) and recovering the beam energy. Energy recovery is achieved by passing the electron beam, following acceleration and x-ray production, back into the linac in the opposite phase to the accelerated beam. The energy in the electron beam is deposited into the SRF cavities, building field for acceleration of fresh beam from the electron source, and providing enormous savings in electrical power. There have been several demonstrations of the ERL technique, most recently at JLab up to 1100 kW average beam power has been recovered in an ERL by recirculating 7.5 mA of beam current at 145 MeV, and up to 9 mA average beam current has been recirculated at 88 MeV. The principle of energy recovery has also been demonstrated at higher energy at CEBAF, where 80  $\mu$ A of cw beam current was accelerated from 20 MeV to 1 GeV, and then stably decelerated back to the injection energy with full energy recovery.

JLab's 12 GeV CEBAF Upgrade project has produced high gradient (20-25 MV/m), high  $Q_0$  ( $> 8 \times 10^9$ ) cw SRF accelerating structures. Tight control and mitigation of microphonics noise remains to be demonstrated.

LBNL and MIT are developing accelerator concepts based on proposed developments of the TESLA technology into the cw operating mode. These facilities are designed for high peak x-ray flux and brightness from FELs using high-quality electron beams accelerated in cw SRF linacs, either recirculating or single-pass.

ANL is conducting a study for future upgrades for the APS storage ring that could include a full energy linac injector followed by an XFEL (Lew, 2002), or an ERL injector (Cho, 2003), both of which benefit from cw SRF R&D for accelerating structures. Either option could provide order of magnitude brightness improvement through short bunches and either CW injection or high injection rates into an ultralow emittance ring (very low lifetime) (Eme, 2001).

Cornell and TJNAF JLab are developing light sources based on x-ray production by spontaneous emission in insertion devices with high coherence achievable from high-brightness electron beams, and using an ERL to achieve high average power. Cornell for example is conducting a study towards a 100 mA, 5 GeV beam with the equivalent of 500 MW of power. At BNL a high-current ERL for electron cooling of the RHIC beams is under construction, with the aim providing of Ampere-scale beams using a superconducting linac. The facility will be operational in 2007, and will include the following:

1. SRF photoinjector providing 1.5 nC bunches at a repetition frequency up to 350 MHz.
2. 1 MW CW klystron at 703.75 MHz for driving the gun.
3. 5-cell linac cavity at 703.75 MHz, designed for ultra-high current (up to ampere level CW) with full damping of HOMs and a loss factor six times smaller than TESLA 1.3 GHz cavity.
4. 50 kW IOT transmitter for the linac cavity.
5. Energy recovery loop for ERL operation.
6. All infrastructures as necessary.

This facility will pursue all the SMTF goals for CW SRF at the frequency of 703.75 MHz with a performance extended to high-current machines. At BNL a high-current ERL for electron cooling of the RHIC beams is under development, with the aim providing of Ampere-scale beams using a superconducting linac.

ANL and LBNL are developing proposals for ultra fast x-ray production in conventional storage rings, using cw SRF cavities. In this scheme, the electron bunches receive a head-tail kick in a cw SRF dipole mode ( $TM_{110}$ ) deflecting cavity, phased such that the beam centroid passes through the cavity at zero phase and receives no perturbation, while the head and tail receive transverse kicks in opposite directions. In a downstream radiating magnet or insertion device, the time-correlated transverse kick results in an angular or spatial distribution of the radiation emitted by electrons along the length of the bunch. The resulting extended x-ray pulse with correlated distribution may be imaged by

asymmetrically-cut crystals or aberration-corrected x-ray optics, to result in an x-ray pulse of approximately picosecond duration. After the bunch radiates, the kick introduced is cancelled by a downstream deflecting cavity. High repetition rates, in principle as high as 500 MHz (ALS bunch rate), may be achievable using this technique, providing an ultrafast x-ray source with characteristics suitable for a variety of time-resolved photoemission and magnetism experiments. Several challenges have emerged in the ANL study, including cavity design and development of adequate cw power sources for high frequencies (S-band) and RF phase stability (Bor, 2005).

For a different application, SRF deflecting cavities have also been under development for the high luminosity colliders at Cornell, KEK, and SLAC, and are often referred to as “crab” cavities. Also, Fermilab has developed a SRF crab cavity for rf-separated Kaon beams. Engineering design and prototype tests were carried out for a 3.9 GHz, 5 MV/m, 13-cell design. A single-cell prototype achieved  $Q_0$   $1e9$  up to 10 MV/m. Work continues on a 5-cell prototype to meet the requirement. (Cham, 2001). ANL and LBNL are developing proposals for ultrafast x-ray production in conventional storage rings, using cw SRF cavities. In this scheme, the electron bunches receive a head-tail kick in a cw SRF dipole mode ( $TM_{110}$ ) deflecting cavity, phased such that the beam centroid passes through the cavity at zero phase and receives no perturbation, while the head and tail receive transverse kicks in opposite directions. The scheme has For a different application, SRF deflecting cavities have also been under development for the high luminosity colliders at SLAC, Cornell, and KEK, and SLAC, and are often referred to as a “crab” cavities. y, phased such that the beam centroid passes through the cavity at zero phase and receives no perturbation, while the head and tail receive transverse kicks in opposite directions. In a downstream radiating magnet or insertion device, the time-correlated transverse kick results in an angular or spatial distribution of the radiation emitted by electrons along the length of the bunch. The resulting extended x-ray pulse with correlated distribution may be imaged by asymmetrically-cut crystals or aberration-corrected x-ray optics, to result in an x-ray pulse of approximately picosecond duration. After the bunch radiates, the kick introduced is cancelled by a downstream deflecting cavity. High repetition rates, in principle as high as 500 MHz (ALS bunch rate), may be achievable using this technique, providing an ultrafast x-ray source with characteristics suitable for a variety of time-resolved photoemission and magnetism experiments. Several challenges have emerged in the ANL study, including cavity design and development of adequate cw power sources for high frequencies (S-band) and RF phase stability (Bor, 2005).

## 6b. Goals for a cw SRF test facility at SMTF

Existing R&D facilities are already addressing many of the outstanding and pressing questions in application of cw SRF in particle accelerators, particularly for accelerating structures. In this proposal the SMTF would provide for experimental study of aspects of both accelerating and deflecting cavity structures and cryomodule performance not specifically addressed by other programs. The SMTF goals may be specifically identified as demonstration of the following:

- High Q values in cw operations of accelerating cavities at 20 MV/m, goal of  $Q_o > 3 \times 10^{10}$
- High Q values in cw operations of deflecting cavities at transverse kick voltage of 5 MV/m, goal of  $Q_o > 5 \times 10^9$
- High stability and control of accelerating fields, goals of phase error  $< 0.01^\circ$  and amplitude error  $< 10^{-4}$
- The above performance in the presence of electron beam of 1 nC charge

This proposal presents a program of experimental investigation of cw SRF not addressed at other facilities within the US.

The first tests at SMTF can also address some of the following important issues:

- Thermal management for a range of projected Q values
- HOM (higher-order modes) and LOM (lower-order modes) damping validation
- Cavity tuning control
- Power coupler designs

Equipment will be required to allow determination of cavity Q values, gradient, stability, HOM and LOM characteristics, thermal load at a variety of locations within the cryomodule, input power, dark current, etc.

In addition, couplers and tuners and other cryomodule components would be fabricated to extend the full range of expertise and technology required for the major projects envisioned. For both deflecting cavities and for accelerating cavities, strong damping of HOM's through specially design couplers is required, and for the deflecting  $TM_{110}$  mode cavities, there is an additional challenge of damping the lower frequency  $TM_{010}$  mode which is expected to have a large impedance and damping the other polarization of the deflecting mode.

Capabilities of the SMTF to facilitate operation of a cw test stand would include ability to explore high gradient cw performance along with Q and dark current measurements without beam. Tuner tests, HOM measurements, and cavity microphonic tuning feedback systems test with the cryomodule would be performed to establish the necessary specifications.

Average beam power requirements for the cw cavity investigations are modest, 1 nC bunch current at as high a repetition rate as possible, and would require an RF photocathode source. Synchronization of the cavity phase to the beam will be required to accurately time the arrival of a bunch in the cavity, and measure the head-tail kick of the beam after passing through the deflecting cavity cryomodule.

The above goals encompass research and development topics critical for the development of cw operation for many proposed applications. For example, the exacting phase and amplitude goals require development of low-level RF systems which would have benefits in many SRF applications. The cryomodule tested at SMTF may be subsequently tested at higher beam currents at Jlab, at BNL or at Cornell.

The cryomodule and cavities may be constructed in US industry, and processed and tested using existing infrastructure at US labs.

The provision for a cw test area in the SMTF would allow R&D into cw SRF cryomodules for accelerating structures and deflecting cavities, required by future linacs, recirculating linac's, high current storage rings, and ERL's. The SMTF would provide a location and infrastructure for development of cw SRF systems to meet these needs and for other future developments, and would be complementary to the existing facilities and R&D programs. Strong intellectual and technical interactions between cw, RIA, PD, and ILC enthusiasts (many of whom are the same people) would be of benefit to all communities.

## 6c. Prototype cw cryomodules for SMTF

We propose two projects for development of cw SRF at SMTF, the first is aimed at improving performance of accelerating cavities and the second at developing deflecting cavities.

For accelerating cavity development in cw applications, the multi-cell cavity for the ILC, at 1.3 GHz, offers an existing design having parameters suitable to application in cw mode to meet the needs of future facilities with modest beam loading ( $\sim 10 \mu\text{A}$ ). To take advantage of developments to date in SCRF, use of the cavity design developed for ILC would provide a suitable prototype to address the performance questions listed above for cw operations. These particular questions are not being addressed at 1.3 GHz at other facilities (BNL is addressing the high-current ERL at 0.704 GHz).

R&D into deflecting cavity design would focus on single-cell cavities operating at the third or fourth S-band, which is anywhere between the 3rd-10th harmonic of typical storage ring RF system. These could provide a deflecting kick of hundreds of kV to MV. The cavities may be used in a cryomodule to providing a transverse kick that may typically be required for storage ring ultrafast x-ray production applications. Operating in the  $\text{TM}_{110}$  mode, the deflecting cavities are deformed by flattening opposite sides (squashing the cavity), such that the two dipole mode polarizations are split in frequency and in spatial orientation. The cavity would be mounted in the accelerator with the desired orientation of the transverse kick axis. The critical design parameters for deflecting cavities are the transverse shunt impedance and the peak surface magnetic field. For the TESLA accelerating cavities, the maximum surface magnetic field is approximately 0.1 T at 25 MV/m, with a theoretical limit about twice that. The cavity gradient is limited by magnetic field quenches, and also by field emission. Careful design will be required to minimize multipacting, and test at the SMTF will be essential to qualify cavities for installation in operating light source user facilities.

We propose to design and build a two-cavity cryomodule for tests of deflecting cavities at the SMTF, for application in storage ring ultrafast x-ray production techniques. Installing two cavities in a cryomodule allows experimentation with adjusting thermal loads, study of HOM and LOM dampers, as well as study of potential "cross-talk" between cavities and components adjacent to each other. The cavities would be designed to operate at a nominal 2K, with possibility of lower temperature tests.

For research and development of high gradient, high quality factor cw accelerating structures, we propose to also build a two-cavity cryomodule. The design would incorporate two of the ILC-like multi-cell cavities mentioned above, into a single cryomodule, distinct from the deflecting cavity cryomodule. Existing designs such as the cryomodule built for the Rossendorf facility may be developed by US industry and institutions for this application.

## Thermal management

The dynamic heat load in the cw SRF cavities is inversely proportional to the cavity unloaded Q value,  $Q_0$ . Typical  $Q_0$  values for L-band dipole  $TM_{110}$  mode cavities are  $\sim$  few  $10^9$ , and an order of magnitude greater for monopole  $TM_{010}$  mode cavities. Development of high Q cavities has significant advantages to cw operations, in reducing RF power requirements. We note that development of  $Q_0 > 3 \times 10^{10}$  for the accelerating monopole mode is particularly important for larger, multi-GeV, linacs, and  $Q_0$  approaching  $10^{10}$  will enhance deflecting cavity operations.

Lowering the temperature to 1.8 K increases the theoretical Q reachable. Excellent magnetic shielding will be necessary to screen the earth's field down to about one mGauss. (The earth's field flux quanta get trapped in the niobium walls, due to the presence of imperfections, impurities and oxides, thereby limiting the Q-value).

Operating at 1.8 K to reduce the BCS resistance and increase the theoretical maximum Q-value will demand larger pumps to reach the lower helium vapor pressure corresponding to 1.8 K. Even though the goal is to reach a Q of  $3 \times 10^{10}$  for the  $TM_{010}$  mode, and in excess of  $5 \times 10^9$  for the  $TM_{110}$  mode, a cw SMTF module should be equipped with features to handle Q values down to a factor three to five lower, so that we may learn how to deal with high heat loads, if the high Q's aimed for are not realized, or partially realized. The Meson cryogenic plant will be able to provide 1.8 K at a reduced capacity.

A  $TM_{010}$  mode cavity operating in cw mode at 20 MV/m with a  $Q_0$  of  $1 \times 10^{10}$  may be expected to generate approximately 40 W heat load at 2 K as a result of RF current flow on the inner surfaces of the cavity. Added to this is approximately 8 W heat entering the cavity niobium body from the input RF power coupler. A 1.5 GHz  $TM_{110}$  cavity operating in cw mode at transverse kick 5 MV/m with a  $Q_0$  of  $2 \times 10^9$  may be expected to generate approximately 10 W heat load at 2 K as a result of RF current flow on the inner surfaces of the cavity. Added to this is possibly 10 W heat entering the cavity niobium body from the input RF power coupler (assuming a coaxial coupler designed to damp the HOMs and LOM). These dynamic heat loads are to be transferred through the niobium to the cavity outer surface in the super-fluid helium liquid bath, then to the super-fluid helium surface where boiling occurs at 1.8 K, without quenching the cavity. In a super-fluid helium test bath there is no problem transferring this heat from the cavity outer surface to the super-fluid helium surface, however, the transport of about 50 W from the cavity outer surface through the helium tank, the feed-pipe and the header-pipe requires careful engineering.

In order to provide sufficient heat transfer from the cavity outer surface to the surface of the liquid in the header, the following cryogenic module design issues are to be addressed:

- The number of feed pipes between the RF cavity helium tank and the two-phase helium stand pipe
- The location of the helium feeds on the helium tank
- The inside diameter of the helium tank relative to the cavity outer diameter, to control the spacing between the cavity convolutions and the cavity helium tank inner wall through which heat must flow
- The diameter of the liquid helium feed pipes from the stand-pipe to the tank
- The diameter of the two-phase helium header pipe

A 1.5 GHz dipole mode cavity operating in cw mode at transverse kick 5 MV/m with a  $Q_0$  of  $2 \times 10^9$  may be expected to generate approximately 10 W heat load at 2 K as a result of RF current flow on the inner surfaces of the cavity. Added to this is possibly 10 W heat entering the cavity niobium body from the input RF power coupler (assuming a coaxial coupler designed to damp the HOMs and LOM).

Lower frequencies also reduce the BCS resistance of a cavity, and other laboratories are pursuing designs based on lower frequencies. This work would be complementary to SMTF.

## Control of cavity HOM's and wakefields

For high average power operations, cavity Higher Order Modes (HOMs) may present significant problems due to the perturbative effects of the wakefields persisting from one electron bunch to the next.

In the case of a dipole mode cavity, there also exists a lower frequency monopole mode, which typically has a large shunt impedance, so in this case we must also address the Lower Order Modes (LOMs). Damping of the LOM without significant coupling to the deflecting mode presents a particular challenge that this program would address. The unwanted dipole mode polarization must also be dealt with – either by tuning its frequency out of harms way, or by selective damping.

Since the SRF cavities require very smooth boundaries and transitions, HOM/LOM damping devices are located at the ends of the cavities, in the beam pipe, and may be in a cold section of the cryomodule or external in a warm section.

Effective HOM/LOM damping is required to reduce resonant beam impedance, raise coupled-bunch instability thresholds, and allow stable operations.

Although the majority of these tests can be meaningfully conducted at high average current facilities, beam tests planned with the SMTF beam would help validate bench measurements of modes and  $Q$ s. These results would be useful input to beam stability assessment for various applications at higher currents.

## Feedback control of cavity tuning variations

A significant problem for the use of superconducting cavities is the fact that systematic as well as random tuning errors are orders of magnitude larger than the intrinsic bandwidth. An example for the systematic part is the detuning by the radiation

pressure forces or Lorentz force detuning, which may be as large as 360 Hz for TESLA cavities at a gradient of 20 MV/m. While this is of great concern for pulsed cavities, it can be easily corrected in the cw application where the field is continuous.

More serious are the random tuning deviations. The random tuning perturbations fall in two categories:

- A. Relatively slow perturbations, with periodic intervals in the minute range. Random variations of the helium pressure represent a common cause.
- B. Fast perturbations due to microphonics in the acoustic frequency range, caused by local mechanical stimuli (pumps, turbulence in the helium flow etc). The response is shaped by structural resonances and directional sensitivities of the cavities.

Slow mechanical tuners may be used to eliminate the slow perturbations. Faster feedback systems are required to control the effects of microphonics, which may extend their influence to approximately  $\pm 25$  Hz from the RF frequency. To control against such rapid tuning variations, the RF system must provide sufficient generator power to establish the nominal field in the cavity under worst-case conditions of full detuning by microphonics.

In addition, the impact of beam loading from a  $\sim 1$  nC charge needs to be investigated. Such a bunch would shock-excite the cavities and introduce transient behavior of the RF fields that must be corrected by feedback systems.

To achieve the maximum possible phase and amplitude performance from these CW SRF systems high gains will be required in the controller feedback loop. Adaptive feed-forward controllers will also be extremely useful for the optimal suppression of periodic perturbations including “microphonic” mechanical vibrations and beam loading. Many labs are working on the development of these controller architectures including LBNL, Cornell, TESLA, JLab JLab and MIT.

The requirement to maintain field in the cavities under the influence of microphonics and beam loading has strong impact on the cavity RF feedback system and RF power requirements, and thus costs. Techniques to minimize detuning from microphonics may have significant impact in cw SRF systems design. Beam loading from orbit offsets in deflecting cavities can be significant and must be controlled or compensated; this also potentially strongly impacts the RF power requirement.

While RF control tests with  $Q_{\text{ext}} > 10^7$  and up to  $10^8$  are presently conducted at the Jefferson Lab FEL without and with beam, demonstration of the more stringent phase stability requirement of 0.01 degrees is likely to await the SMTF.

To achieve the precision phase stability of 0.01 degrees the SMTF must deliver a master RF timing distribution system with such accuracy or better. The reference “clock” must perform as well as or better than the device to be regulated. New RF synchronization designs which make use of short pulse laser systems offer the potential to meet these requirements. The ILC component of the SMTF should demonstrate Master Oscillator and RF distribution systems which maintain a precision of 1 degree when

projected to ILC length scales of 30 km. This requirement is similar to the 0.01 degree goal for the CW section of the SMTF which will have a length scale between 10-100 m.

## Power couplers

Superconducting RF systems require very little power to generate large accelerating gradients – for example the TESLA cavities may develop 20 MV/m with only 40 W input power under ideal conditions. In order to accommodate for tuning variations as discussed above, however, significantly larger RF drive power is required at the lower external  $Q$ , typically tens of kW per cavity for  $Q_{\text{ext}} \approx 10^7$ .

For dipole mode operation, there may be need to accommodate beam offset from the mode axis, in which case the beam experiences the longitudinal field of the dipole mode, and also deposits power into the cavity. Additional drive power may be required to compensate for this beam loading in high-current applications, but is not expected to be a necessity in tests at SMTF.

Power couplers must transport this 10's kW power from warm waveguide or coaxial supply lines, through intermediate temperatures, thermally isolating sections, vacuum windows, to liquid helium temperature components, and have mechanically adjustable components, while avoiding multipacting and excessive heating. Choice of coaxial or radial coupling arrangements will be made in the design stage.

## RF Transmitters

As described above, the intrinsic power demand for an SRF cavity operating at 20 MV/m,  $Q_0 = 10^{10}$  and 100  $\mu\text{A}$  beam current is only 2040 Watts. The remainder of the power from a 10 kW power source is reflected from the cavity structure and absorbed in an external load. This additional power is required to maintain adequate control of the cavity fields. Innovative transmitter designs including low insertion loss external reactive tuners offer the potential to reduce the power demand by factors of two or more. These reactive tuners are also the same devices that could be used for individual cavity control in the ILC configuration where a large 10 MW klystron feeds 32 cavities through a waveguide distribution system. Successful testing of these efficient amplifier systems at SMTF will benefit many existing and proposed accelerator facilities.

Compensation of beam loading and microphonics in deflecting cavity applications may require several 10s of kW cw RF power. Commercially available cw RF power transmitters in the S-band, above 2.6 GHz in particular, are not adequate. Although the specific RF frequency is to be determined by the application, through this SMTF initiative it is of benefit to the accelerator community to develop cw RF power transmitters over a range of RF frequencies and power levels using a modular approach.

## 6d. Infrastructure requirements for a cw SRF test facility

The SMTF should provide capability for measurements of cw SRF cryomodules, with the installation of RF power, cryogenic fluids and transport, and test beams of electrons.

The accelerating  $TM_{010}$  cavity tests will require, for each cavity, a 1.3 GHz klystron (or IOT) with approximately 15 KW of power to establish 20 MV/m operating field with control margin for dealing with microphonics at the optimum external Q value, estimated to be about  $2 \times 10^7$ . A high voltage power supply and a small amplifier are needed to supply the klystron. We envision testing cryomodules initially with two cavities per cryomodule.

For deflecting cavities, the operating frequency depends on the application. Funding for the RF power components for this application would be provided from the project source, and it is expected that the systems would be removed for operation at the host institution following tests at SMTF. The SMTF should reserve space in the cw area to accommodate additional RF power requirements such as this.

The more demanding possibility of testing cw accelerating cavities at cw at 20 MV/m with Q of  $1 \times 10^{10}$  would require 60 W/m at 2 K allowing for a safety factor of 1.5. Assuming advances in technology would triple the obtainable Q value, the cw cryomodule refrigerator would be sized for 20 W/m at 1.8 K and about 5 W/m at 4.5 K. However, to ensure capabilities in early design stages, where the higher  $Q_0$  values may not be initially obtained, the cryogenics plant should be designed with capacity of 120 W at 2 K, allowing two accelerating cavities to operate with a 50% design margin on cooling capacity.

Electron beam availability is highly desirable for measurement of cavity performance under transient effects induced by bunches of 1 nC. Cavity voltage and phase, and wakefields in the complicated electrodynamic environment of cavities assembled in a cryomodule would be essential in gaining confidence for employing cw SRF in demanding light-source applications. Bunch lengths of 1 – 10 ps, and transverse emittance of order mm-mrad would be of interest. The proposed integration of the FNPL facility into SMTF would provide beams useful for testing cw cavities. Alternatively, a DC photoinjector could provide low current beams at MHz repetition rates allowing precision measurements of the cavity fields with a higher bandwidth probe.

In addition to RF power and cryogenics, the cw facility would require technical support from the SMTF. To build the RF systems at SMTF would require 1 FTE electrical engineer, 1.5 FTE electrical technicians, 1 FTE mechanical technician. To support the installation, test, and operations of two cryomodules proposed would require from SMTF approximately 0.5 FTE cryogenics engineer, 1 FTE mechanical technician, 0.5 FTE controls/electrical technician, 0.5 FTE vacuum technician.

The CW component of the SMTF will also have significant availability requirements. For the facility to be effective in its research goals operation must be available in excess of 3 months per year with operational duration of at least two weeks and availability in every three month calendar interval.

## Institutional and industrial involvement in the cw program at SMTF

Several institutions have been mentioned as having interests in cw scrf, and some have experimental programs independent and complementary to SMTF. For the two programs proposed here, we envision a collaboration of institutions interested in light source development, and industry with capabilities and interests in superconducting RF structure fabrication, and cryomodule fabrication.

The institutional involvement will likely include Lawrence Berkeley National Laboratory, Cornell University, Thomas Jefferson Laboratory, Massachusetts Institute of Technology Bates Linear Accelerator Center, Argonne National Laboratory, Brookhaven National Laboratory, and Stanford Synchrotron Radiation Laboratory.

JLab in particular currently represents a major fraction of DoE's existing investment in SRF technology. As a result of this investment the capability exists for producing and delivering accelerating structures and components from concepts to prototypes. With the existing LLRF and high power capabilities, JLab is in a position to deliver an entire vertical slice of a cw SRF module for testing at SMTF or JLab, as appropriate.

## Relationship to International activities

Several institutions worldwide outside the US are active in research and development of cw scrf, and several proposals for applications in accelerators are being pursued. We note here the ELBE facility at Rossendorf, Germany, the 4GLS project at Daresbury, England, and the BESSY FEL proposal from Berlin, Germany.

At the ELBE radiation source in Rossendorf, TESLA technology has been used in developing cryomodules in collaboration with Stanford University, housing two cavities operating in cw mode. Gradients of 15 MV/m are routinely achieved in operations.

The 4GLS project is based on an energy recovery linac (ERL) using cw scrf. An ERL prototype (ERLP) is being constructed at Daresbury, using accelerating systems with two TESLA cavities per cryomodule to provide up to 30 MeV energy gain from the 2m active RF structures.

The BESSY Soft X-ray FEL proposes to use a single-pass cw SRF linac based on developments of the TESLA technology to achieve 15-20 MV/m accelerating gradient, to accelerate electron bunches up to 2.3 GeV, with a beam power of up to 150 kW.

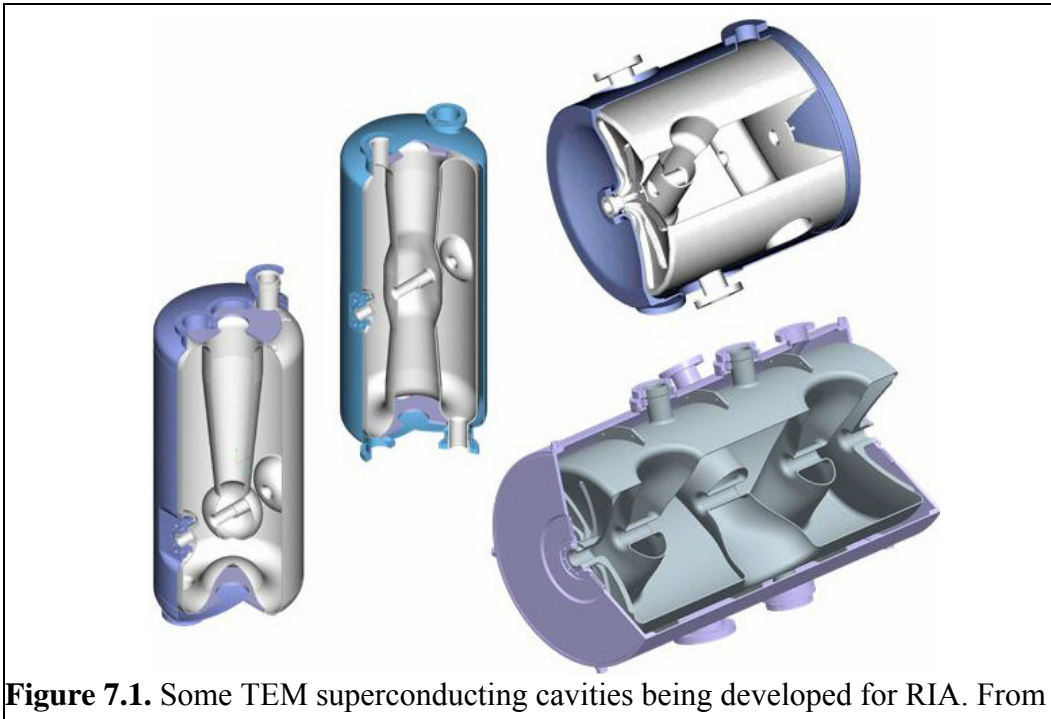
KEK has developed two single-cell, 508 MHz, 1.4 MV (5.6 MV/m) SRF deflecting (crab) cavities for installation in the KEK B-factory in 2005.

## 7. RIA Cavity and Cryomodule Test Facilities

The U.S. Rare Isotope Accelerator Project (RIA) will include the construction of roughly 500 superconducting cavities of as many as 10 different types to accelerate ions over a velocity range  $0.02 < \beta < 0.85$ . These cavity types will include TEM-class cavities such as those shown in Figure 6. RIA will require facilities to clean and test the individual cavities and also facilities to clean, assemble, and test cavity strings and cryomodules. Not all of these facilities need be at the RIA site, and some could in principle be included in SMTF. This said, however, proximity to the RIA site would be useful in simplifying transport and storage issues.

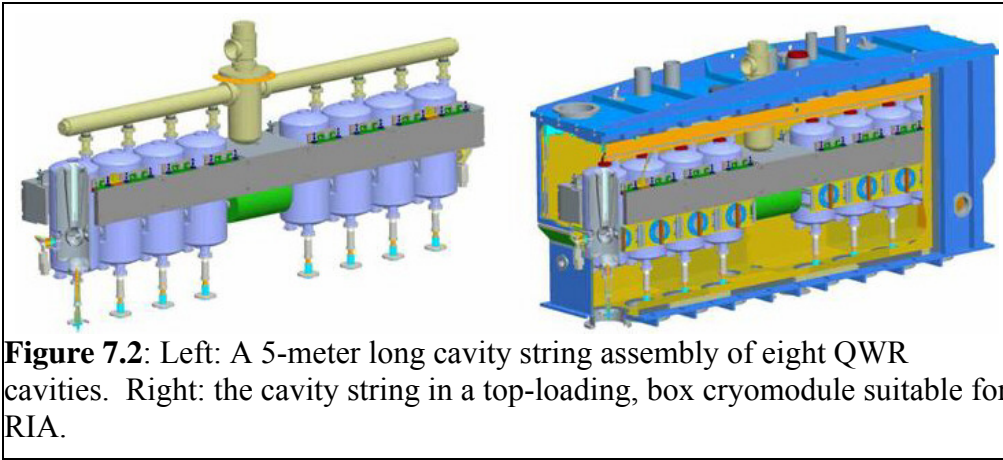
Recent development of TEM-class, drift-tube cavities for RIA has achieved new levels of performance by adapting ultra-clean surface preparation techniques originally developed for TESLA velocity-of-light structures to TEM cavities. This convergence of SRF technology of low-velocity structures with that of high-velocity structures opens a possibility of a processing and test facility being able to serve the needs of both communities.

If SMTF can in fact be structured to accommodate such a broad range of cavity types, it would be a unique facility in bringing together under one roof the practitioners of several different types of SRF technology. The opportunity thus afforded for discussion and sharing of technical problems



**Figure 7.1.** Some TEM superconducting cavities being developed for RIA. From

and solutions on a daily, nuts and bolts level amongst groups with different experience and perspective could create a fertile and creative environment for SRF development.



**Figure 7.2:** Left: A 5-meter long cavity string assembly of eight QWR cavities. Right: the cavity string in a top-loading, box cryomodule suitable for RIA.

Within the RIA project there will be several classes of task that could possibly be accommodated at SMTF:

- 1) Cleaning and cold-testing of individual cavities, after chemical processing
- 2) Clean assembly of cavities into cavity strings, forming a sealed assembly including RF couplers, beam line valves, and vacuum manifold and valves.
- 3) Assembly of cryomodules incorporating the cavity strings.
- 4) Cold test of assembled cryomodules.

A number of resources will be required to perform the above tasks at SMTF. Some are similar to those required for other groups of users, such as clean areas with provision for ultrasonic cleaning and high pressure rinsing with ultra-pure water and clean storage for cavities and associated components.

Because RIA uses low-frequency cavities which can operate at higher temperatures than velocity of light structures, 4 K refrigeration at the level of a few hundred watts will be needed for both single-cavity and cryomodule cold-test capability. For single-cavity tests the ability to operate at 2 K is needed, and also possibly for cryomodule tests with 805 MHz elliptical-cell cavities.

Single-cavity test cryostats and cryomodule test areas will need a 10-ton overhead crane for set-up and assembly, and will required 18 inches or more of concrete shielding or equivalent to shield the x-rays resulting from high-field operation.

CW RF power at the level of 1-2 kilowatts will be required at several different frequencies to test the different types of cavities required. A single-cavity test cryostat can be designed to test most if not all of the different cavity types and frequencies, but several RF sources will be required. For one of the configurations of the RIA driver being considered, RF power at 57, 115, 172, and 345 MHz would be needed

The facilities for RIA would overlap to some extent with those required for the front end of the proposed FNAL proton driver, which will also require TEM-class cavities operating at 4.2K. The principal difference is that for the proton driver the cavities will be operated in a pulsed mode rather than cw, but the cavity types, cryomodules, couplers, and tuners are likely to be similar in design.

Table 7.1 shows the resources that will be needed for various tasks during the construction of RIA, which is expected to extend over three year period.

In addition to the floor space detailed in Table 7.1, some area, possibly a few thousand square feet, will be needed for the storage of incoming parts and sub-assemblies. The lab and office space are for a cryomodule test and assembly team estimated at 30 – 35 people.

**Table 7.1.** Some estimates of the facilities required for several RIA project tasks

	<b>Lab/ Office</b>	<b>Clean Area</b>	<b>High- bay</b>	<b>Refrigeration</b>	<b>Other</b>
<b>Single Cavity Tests</b>	1000 ft <sup>2</sup>	1000 ft <sup>2</sup>	1000 ft <sup>2</sup>	250 w at 4K, 100 w at 2K	RF power, control area, incoming parts storage
<b>String Assembly</b>	2600 ft <sup>2</sup>	2700 ft <sup>2</sup>	-	-	Class 100 clean area, incoming parts storage
<b>Cryo-string Assembly and Alignment</b>	2800 ft <sup>2</sup>	2300 ft <sup>2</sup>	-	-	Class 10000 clean area, high-bay staging area
<b>Cryomodule Cold Test</b>	1800 ft <sup>2</sup>	-	3600 ft <sup>2</sup>	1000 w at 4K, 250 w at 2K	RF power, control area, 10 ton OH crane
<b>TOTAL</b>	<b>8200 ft<sup>2</sup></b>	<b>6000 ft<sup>2</sup></b>	<b>4600 ft<sup>2</sup></b>	<b>1250 w at 4K, 350 w at 2K</b>	

# 8. Electron beam: Fermilab/NICADD Photo Injector and Upgrade

## Introduction

Since 1992, Fermilab has been engaged in the production of high-brightness electron beam<sup>1</sup>. In conjunction with the TESLA collaboration, it has constructed and operated an L-band (1.3 GHz) photo injector, a copy of which was installed at the TESLA test facility in DESY Hamburg, for various tests, especially for the proof-of-principle UV SASE free-electron laser experiment<sup>2</sup>. The Fermilab/NICADD photo injector laboratory (FNPL) is used as a test facility for beam dynamics studies associated to high brightness beam and its associated diagnosis, along with application to advanced accelerator physics.

The photo-injector will be moved to SMTF and will be upgraded in a phased approach. The present plan at AØ is to reconfigure the injector to include: a normal conducting gun, and two TESLA cavities (one operating at 12 MV/m and one at 25 MV/m). This configuration requires a high power klystron/modulator system (~4-5 MW) for the normal conducting gun, and two low power systems (~300 KW nominal each) for the two TESLA cavities. Both the gun and the modulator would need to be upgraded for 5 Hz long pulse operation.

A further step would incorporate two 3.9 GHz cavities of two different designs, presently under development. One of these cavity types (3<sup>rd</sup> Harmonic) is operated in deceleration mode and linearizes the beam bunch energy with time<sup>3</sup>. The other operates in a deflecting mode<sup>4</sup> and is used as a diagnostic to measure beam properties within the different time slices of the beam bunch. The cavities require ~4 kW power. To implement these two cavities requires two additional low power modulators; one of which is similar to that needed for the individual TESLA cavities (above), and one that is a gated CW modulator.

Eventually it might be desirable to upgrade the injector to a system similar to that now at TTF<sup>5</sup>. The two TESLA cavities would be replaced by an eight cavity module with some of the cavities operating at ~12MV/m and the rest at ~25 MV/m. Alternatively the module could be in addition to the two cavities, and installed downstream of them. This module would require a high power (5 MW) klystron/modulator system. The one 3.9 GHz decelerating cavity would be replaced by a module of four 3<sup>rd</sup> Harmonic cavities and would require an 80 KW klystron that could actually be the same unit as before, but operated at higher power.

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<sup>1</sup> See for details <http://nicadd.niu.edu/fnpl>

<sup>2</sup> V. Ayvazyan, et al, Phys. Rev. Lett. **88**, 104802 (2002)

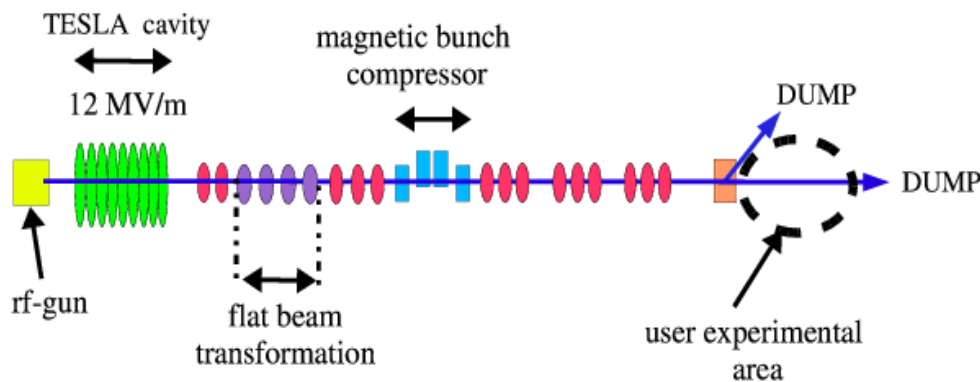
<sup>3</sup> N. Solyak, et al., in *Proceedings of the 2003 Particle Accelerator Conference, Portland OR*, IEEE Publishing, Piscataway, New Jersey, p. 1213 (2003)

<sup>4</sup> L. Bellantoni et al, in *Proceedings of the 2001 Particle Accelerator Conference, Chicago IL*, IEEE Publishing, Piscataway, New Jersey, p. 1077 (2001)

<sup>5</sup> K. Flöttmann and P. Piot, in *Proceedings of the 2002 European Particle Accelerator Conference, Paris*, IOP publishing, p. 1798 (2002)

## Facility and existing capabilities

FNPL consists of a 1+1/2 cell L-band RF-gun equipped with a high quantum efficiency Cesium-Telluride photo-cathode allowing the photo-emission of electron bunches with charge up to  $\sim 15$  nC. The generated bunches are further accelerated, up to 16 MeV, by a downstream superconducting TESLA cavity operating with a nominal accelerating gradient of  $\sim 12$  MV/m (see Fig.8.1). Downstream of the cavity the beam line includes a set of quadrupoles and steering dipoles elements for beam focusing and orbit correction, a skew quadrupole channel that allows the generation of flat beam using an incoming angular-momentum dominated beam, and a magnetic bunch compressor chicane which can enhance the bunch peak current up to approximately 2.5 kA. The diagnostics for measuring transverse beam properties consist of electromagnetic beam position monitors, optical transition radiation (or YAG) screens (for measuring beam transverse density) and three emittance measurements station based on the multi-slit mask technique. The bunch length measurement is performed by a streak camera that streaks optical transition radiation pulses emitted by the bunch. An alternative frequency-domain bunch length diagnostics based on Martin-Puplett interferometer of coherent transition radiation is also available. Downstream of the beamline, the beam can be bent in a dispersive section, to measure the beam energy distribution, or transported in a straight ahead user experimental area. The FNPL facility can be operated remotely. So far teams from LBNL and DESY have used this capability to remotely perform beam physics experiments.



**Figure 8.1: Overview of the FNPL facility in its present configuration in the AØ building at Fermilab.**

## Current activities

Several advanced beam dynamics and beam diagnostics activities are being actively pursued at the FNPL photo-injector. Our main current efforts are (1) photo-injector production of angular-momentum-dominated electron beams<sup>6</sup> and subsequent generation of a flat beam with high transverse emittance ratio<sup>7</sup>, (2) longitudinal beam dynamics

<sup>6</sup> Y.-E Sun, P. Piot, *et al.*, Phys. Rev. ST Accel. & Beam **7**, 123501 (2004)

<sup>7</sup> D. Edwards *et al.*, in proceedings of the XX international Linac Conference, Monterey CA, (SLAC, Stanford 2000), p.122 (2000)

studies using a two macro-particle bunch<sup>8</sup>, (3) study of emittance control versus shape of the photo-cathode drive-laser, (4) emittance evolution of highly charge electron bunches for different photocathode laser parameter, and (5) R&D on instrumentation (currently characterization of a bunch length monitor based on coherent transition radiation). All these experimental studies also involve theoretical and numerical modeling.

Collaborators from NIU and UCLA have been performing experiment on plasma-wake field acceleration. The experiment consists of injecting a high charge (typically 10 nC) short (typically 3 ps) electron bunch in Argon plasma. The experiment has both concentrated on demonstrating beam plasma deceleration and acceleration. From this experiment the amplitude of the accelerating plasma wake-field has been measured to be 130 MV/m. Our UCLA collaborators have recently installed an experiment devoted to realize an electron source based on the so-called plasma-density transition. A first set of experiments were attempted<sup>9</sup> and the experimental apparatus is now being used to study focusing properties of a plasma lens operating in the under-dense regime.

A team from the University of Rochester has developed a laser functioning on the TM<sub>01</sub>\* mode, a mode with a longitudinal electric field component. The laser is now ready and we plan, after the foreseen energy upgrade of FNPL (see next section), to “couple” the laser and electron beams with an open iris structure. At energies above 40 MeV, we will be able to observed laser-based acceleration<sup>10</sup>.

The Urbana-Champaign team will install (in spring 2005) a fast kicker to make a mockup experiment aiming to test how precise the rising time of the kicker can be measured<sup>11</sup>. A fast kicker prototype being considered for a short damping ring design will then be installed and characterized with beam.

A collaboration consisting of NIU, University of Rochester and FNAL has started a program aimed to measure bunch length and time profile of sub-picosecond bunch using the electro-optical sampling technique. Our current objective is to re-install, during spring 2005, the original experiment performed at FNPL<sup>12</sup> and then gradually improve the experimental setup.

## Upgrade Plans

The TESLA collaboration has recently offered to provide a second TESLA cavity with an accelerating above 30 MV/m. We plan to install this second cavity downstream of the first one to boost the beam energy to approximately 45 MeV. Such an energy increase (by a factor ~3 compared to the present setup) will considerably reduce the impact of space-

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<sup>8</sup> R. Tikhoplav *et al.*, in proceedings of the XXII international Linac Conference, Lübeck, Germany (2004) preprint available at <http://bel.gsi.de/linac2004/PAPERS/MOP46.pdf>

<sup>9</sup> M. Thompson *et al.*, Status of the UCLA/NICADD plasma density transition trapping experiment, Conf. Proceeding of the 11<sup>th</sup> Advanced accelerator concept workshop AIP Conf. Proc. **737**, p 440 (2004)

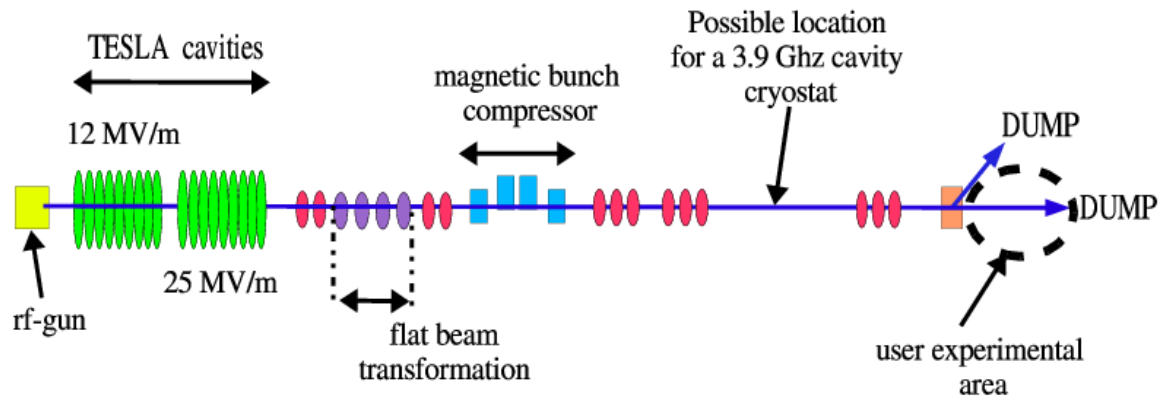
<sup>10</sup> R. Tikhoplav, *et al.*, in *Proceedings of the 2002 European Particle Accelerator Conference*, Paris, IOP publishing, p. 984 (2002)

<sup>11</sup> G. Gollin, expression of interest available [http://www.hep.uiuc.edu/home/g-gollin/Linear\\_collider/A0\\_committee\\_presentation.pdf](http://www.hep.uiuc.edu/home/g-gollin/Linear_collider/A0_committee_presentation.pdf)

<sup>12</sup> M. Fitch, et al, Phys. Rev. Lett. **87**, 034801 (2001)

charge forces ( $\propto 1/\gamma^2$ ) on the beam dynamics and thereby resulting in a better control of transverse envelope and emittance. The FNPL upgrade will also allow the support of variety of “user experiment” discussed later in the present Chapter.

In the process of this beamline extension, and given the space constraint in the AØ building, we currently plan to also configure the beamline to allocate room for one of the 3.9 GHz cavity being developed at FNAL (either the deflecting or accelerating mode). The deflecting mode cavity was initially designed in the context of the Kaon separation out of the secondary beam produced at the main injector at FNAL (so-called CKM experiment). It has also applications in the LUX proposal at LBNL<sup>13</sup> to generate ultra-short X-ray pulses. The accelerating mode cavity was developed to linearize the longitudinal phase space prior to a magnetic bunch compressor<sup>14</sup> and thereby enhance the peak current (after magnetic compression) in an accelerator working on the 1.3 GHz frequency. Such a “linearizer” has applications in the context of light source (TESLA VUV/X-ray FELs, LUX project at LBNL, etc...) and also linear collider (TESLA post damping ring bunch compressor<sup>15</sup>).



**Figure 8.2: Overview of the upgraded FNPL facility. The facility will incorporate two TESLA cavities, and a location for testing any of the two 3.9 GHz cavities being developed at FNAL.**

At FNPL the use of the deflecting mode cavity would provide a unique diagnostics that would allow the measurement of beam parameters within the bunch (so-called slice parameters) and result in a more complete picture of the beam dynamics of space-charge-dominated electron beams. A schematic of the proposed FNPL upgrade is shown in Figure 8.2.

### FNPL upgrade as an e- injector for SMTF

In the context of SMTF, the upgraded version of FNPL would provide an ideal injector that could, at a later stage, be transplanted on the SMTF site. We envision three phases for the photo-injector (see Figure 8.3):

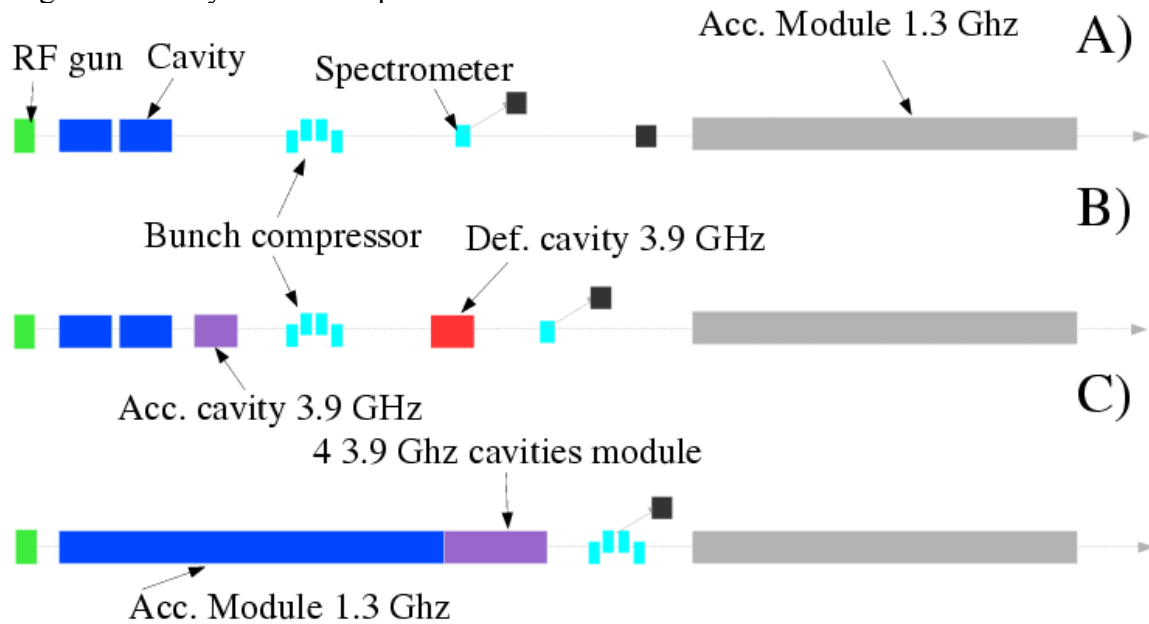
<sup>13</sup> LUX informations are available at <http://lux.lbl.gov>. The idea of generating ultra-short pulse based on the use of a deflecting cavity was introduced in A. Zholents et, Nucl. Instr. Meth. **A425**, p. 385 (1999).

<sup>14</sup> See for instance K. Flöttmann, T. Limberg and P. Piot, DESY report TESLA-FEL-01-06 (2001)

<sup>15</sup> P. Piot, and W. Decking, A modified post damping ring bunch compressor beamline for the TESLA linear collider, FNAL TM-2235 (March 2004)

- Installation of the FNPL upgraded injector on the SMTF site (phase A),
- Installation of a 3.9 GHz rf-system (both an accelerating and a deflecting mode cavities) in the injector (phase B),
- Replacement of the injector cavities by an eight-cavity accelerating module (phase C).

We now describe each of the injector phase with their capabilities in more details. It should be noted that the detailed numerical simulation and optimization of the different stages have not yet been completed.



**Figure 8.3: proposed staged upgrade for the photo- injector. The FNPL energy upgraded injector will be installed upstream of a cryomodule (A). The 3.9 GHz accelerating and dipole mode cavities will be incorporated in the injector (B). At a later stage, the accelerating section (two TESLA cavities) of the injector will be replaced by a standard 8-cavity accelerating module.**

**Injector Phase A:** A configuration consisting of an RF gun followed by the two TESLA cavities, as planned to be operated at FNPL, would provide a transverse emittance-compensated beam. According to preliminary numerical studies, such a beam could then be subsequently accelerated by a TESLA accelerating module operated at any accelerating gradient without significantly impacting the transverse emittance. Such a feature means that an injector consisting of an rf-gun with two TESLA cavities only (in the present case operated at 12 and 25 MV/m average accelerating gradient) would be an independent entity that could provide controllable beam parameters to be injected in SMTF. The current FNPL facility (one RF-gun followed by one TESLA cavity) does not provide such a capability: the beam is still space-charge-dominated: even over a short drift the beam parameters tend to degrade. Therefore FNPL upgrade, while enabling the extension of the current advanced accelerator physics program, could also be viewed as the first phase of SMTF. Parametric studies and subsequent optimization of the system should allow the production of high quality beam. The FNPL upgrade will also provide

operational experience (e.g. with a new rf-control system) and training for future scientist working at SMTF. We anticipate the upgrade of FNPL (to be ready for SMTF) to include: the installation of the TESLA cavity offered by DESY, an upgrade of the photocathode drive-laser<sup>16</sup> (to improve the reliability of the facility), an upgrade of the modulator, an improved RF gun, to support greater beam duty factor and minor upgrades of the beamlines (especially the bunch compressor and the spectrometer dipole). We should note that the only presently foreseen difference between SMTF injector phase A and FNPL upgrade might be the location of the rf-gun and the first accelerating cavity (this is based on extensive simulation work done for XFEL injector at DESY<sup>17</sup>). The upgraded version of FNPL [along with space allocation for the 3.9 GHz cavities (see phase B)] will take about 20 meters (distance referenced with respect to the cathode), we therefore need additional magnets to transport the beam up to the accelerating module (straight section located between the spectrometer and the entrance of the accelerating module in Fig. 8.3 A). We suggest specifying the magnets (quadrupole and corrector magnets) for a beam energy of ~200 MeV. Such magnets could then be reused in phase C for the bunch compressor area located downstream of the first accelerating module (see Fig. 3 C). The detail transport has not yet been worked out but we suggest the use of 15 quadrupoles and 7 pairs of steerers [these numbers are also based on preliminary consideration for phase C (including spares)].

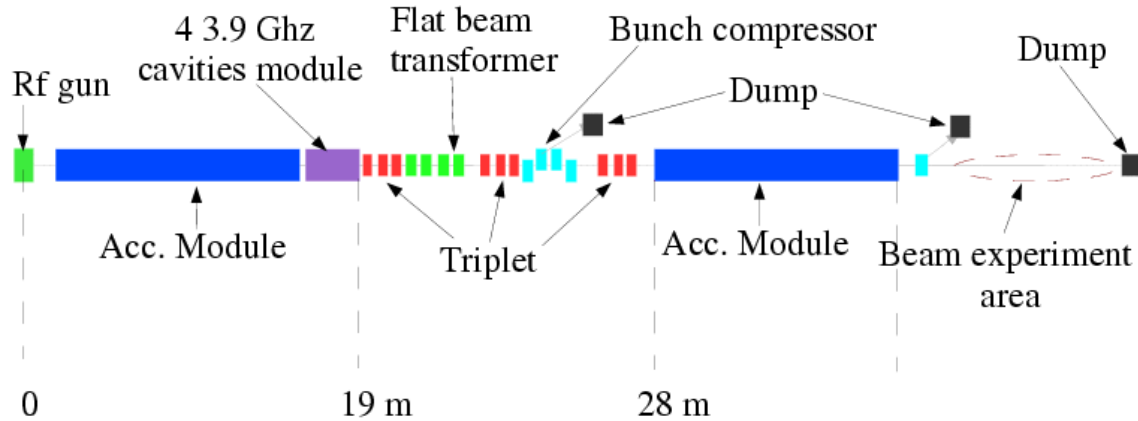
**Injector Phase B:** A second phase of the injector will include the two 3.9 GHz cavities being developed at FNAL. The accelerating cavity together with the magnetic bunch compressor located before the accelerating module (schematic B in Figure 3) will provide SMTF with high peak current bunches that could be use for wakefield measurement or for user applications (e.g. laser or plasma wakefield acceleration) after accelerating in the module. The deflecting cavity will be installed just downstream of the bunch compressor and will provide measurement of the bunch length and slice parameters within the bunch. It will also serve as a diagnostics for properly setting the 3.9 GHz accelerating cavity phase and amplitude for optimum compression. Apart from minor beamline reorganization we do not expect other major changes.

**Injector Phase C:** The final stage of the injector evolution will consist in replacing the accelerating section and low energy transport and diagnostics sections by a standard accelerating module (schematics C in Figure 8.3). At this stage the bunch after generation in the rf-gun will be directly injected in an accelerating module and accelerated to approximately 150 MeV. The bunch will then be compressed using a magnetic chicane and further accelerated in the second (original) accelerating module. Such a configuration will be similar to the TTF VUV FEL injector. The installation of a 3.9 GHz accelerating module (consisting of four cavities) prior to the bunch compressor will enable the generation of high peak current electron bunch. The magnets used in phase A and B between the spectrometer and entrance of the original accelerating module will be recycled in phase C for the optic needed in the bunch compressor area (see Fig 8.4).

<sup>16</sup> A new laser oscillator has been procured by NIU and the upgrade of the laser will happen in spring 2005 following the proposal by N. Barov, J. Li, and R. Tikhoplav, Beams Document 1342-v2 (August 2004) (document available at [http://beamdocs.fnal.gov/DocDB/0013/001342/002/oscillator\\_final.pdf](http://beamdocs.fnal.gov/DocDB/0013/001342/002/oscillator_final.pdf))

<sup>17</sup> K. Flöttmann, P. Piot, M. Ferrario, T. Limberg and B. Grygorian, in *Proceedings of the 2001 Particle Accelerator Conference*, Chicago IL, p. 2236 (2001)

Presently we envision the bunch compressor area to include 3 triplets for transverse beam size control before and after the bunch compressor, and a round-to-flat beam transformer consisting of (3 or 4) quadrupoles enabling the production of flat beam from an incoming magnetized beam. For phase C, we will need to upgrade the bunch compressor dipoles to be able to bend the higher energy beam (150-200 MeV in phase C compared to 40-50 MeV in phases A and B). The high energy dumps located downstream of the second accelerating section should be specified for 1 GeV (up to about 1.3 GeV) so to be also usable downstream of the fourth module (ILC test string) at a latter stage of the SMTF project.



**Figure 8.4: Overview of a possible layout for the final stage of the injector (phase C). The distances (in meter) are estimates based on the TTF VUV FEL design.**

In parallel to the staged evolution of the injector (phases A to C), we strongly recommend the development and construction of a new symmetric RF-gun cavity similar to the one in operation at the TTF VUV FEL facility<sup>18</sup>. The latter rf-gun could be installed in the SMTF injector at any stage.

As presently conceived the CW module would be located downstream of the  $\beta = 1$  accelerating modules in the region called experimental area.

The RF power Requirements for each injector phase are:

- Phase A- one 15 MW modulator (B2), one 5 MW klystron
  - two 600 KW modulators (S1, S2), two 300 KW klystrons
- Phase B- Phase A plus – one 600 KW modulator (S3), one 80 KW 3.9 GHz klystron
  - one 6 KW special modulator (SS4), one 3KW 3.9 GHz kly
- Phase C- two 15 MW modulators (B2, B4 new), two 5 MW klystrons
  - The two 3.9 GHz systems as above in Phase B.

Injector Phase A, B

- Finish building one 170 KW modulator (S3),
- Rebuild two 300 KW klystrons

<sup>18</sup> B. Dwersteg, K. Floettmann, J. Sekutovicz, and Ch. Stolzenburg, *Nucl. Instr. Meth.* **A393**, p. 93 (1997)

## Injector Phase C

- Build one new prototype modulator
- Procure one 10 MW multibeam klystron

### Injector RF Systems Table

System	Phase	Cavity	Klystron nominal power	Klystron status	Modulator	Modulator status
Injector	1	NC gun	Thales TH2104C 5 MW	Exists	15 MWatt “Big”	exists needs upgrade
		Tesla cavity 1	Phillips YK 1240 300KW	Exists	600 kWatt “Small 1”	exists, planning to rebuild
		Tesla cavity 2	Phillips YK 1240 300KW	exists, under rebuild	600 kWatt “Small 2”	under fab/parts procure
		3 <sup>rd</sup> Harmonic	CPI VA 908K2 80 KW	In fabrication	600 kWatt “Small 3”	under fab/parts procure
		3.9GHz Def (CKM)	CPI VKC 7810F 3KW	Exists	“ CW”	under fab
Injector	3 same as 2 with upgrade					
Injector upgrade 1.3	3	8 cavity module	Thales TH2104C 5 MW	need or use TH2095A	15 MWatt “Big”	Need
Injector upgrade 3.9	3	4 cavity 3rd Harmonic 3.9GHz module replaces single cavity	same RF as before CPI VA 908K2 80 KW	may need 2nd Klystron	same mod as before 600 kWatt “Small 3”	

## 9. Cavity and Cryomodule Fabrication Infrastructure

Considerable superconducting cavity and cryomodule infrastructure exists and is spread amongst a number of US laboratories. Nevertheless substantial upgrades are needed at these facilities and at Fermilab in order to develop and exploit state-of-the-art advances in SRF technologies. We intend to build upon the existing infrastructure in a collaborative way to construct several cryomodules. The SMTF concept is based on collaboration between industry, laboratories and universities. Resources and expertise will be shared. The SMTF collaboration has developed and agreed to a cavity and cryomodule fabrication plan that utilizes the existing distributed infrastructure and identifies the needed upgrades. This plan significantly minimizes the cost and advances the schedule. This plan is expected to evolve once the process has begun.

We propose to build the dressed US cavities as a collaboration of industry, Cornell University and Jlab. Initial cavity fabrication and vertical testing will be led by Cornell in collaboration with industry. The cavities would be electro-polished at Jlab. JLab will dress the cavities and send them to Fermilab. The infrastructure at Cornell and JLab will need upgrading. In order to carry out the SMTF program outlined in this proposal, the infrastructure at Fermilab will need to be substantially augmented. The near term Fermilab infrastructure will include a horizontal test stand and the capability to assembly cavities into strings for insertion into cryomodules.

The long term goal is to have the overall general capability to carry on a small research program and have the capability to prepare, process (chemical and electropolish), and test (vertical and horizontal) cavities at the level of one to two per month, consistent with a limited research and development program.

In discussion with the collaborating institutes we have developed a plan for the near term. This plan addresses how to proceed on two modules, the DESY-Fermilab and ILC modules. The parts for the DESY-Fermilab module will be supplied by DESY. The most feasible plan at this point appears to have DESY test the dressed cavities in their CHECHIA cryostat (single cavity horizontal test cryostat) and then ship the tested and sealed cavities to Fermilab. In addition they ship the additional components needed to build the full cryomodule. At Fermilab, the dressed cavities are assembled into eight cavity strings, mounted to the helium header and assembled into the cold mass outer cryostat.

The critical part of this assembly takes place in a class 10 clean room environment. The cavities exteriors must be cleaned of particles before entering the clean room, then the end flanges carefully removed and cavities, bellows, gate valves, and quadrupole assembled under best achievable clean room procedures. This is a step that will give important learning experience to the Fermilab assembly staff. Once the ends of the string are sealed, the string can be removed from the clean room. The string is mounted to the 300 mm helium header and the tuners and magnetic shielding is mounted. Then the

assembly is inserted into the outer cryostat vacuum vessel and the warm parts of the couplers are mounted.

The main infrastructure needed for the proceeding operations is:

- A class 10 clean room of about 10 ft x 50 ft
- Particle free vacuum and leak detection equipment
- Miscellaneous Clean Room support equipment (e.g. Ultra Pure Water, Ultra Sound tanks, Nitrogen gas, particle detectors, etc). and for the string and module assembly
- Miscellaneous fixtures and tooling.

Fermilab will develop a cryomodule assembly facility at MP9. This is the minimal investment needed to assemble cryomodule module and is discussed in more detail in the cryomodule assembly section.

The plan for the first ILC module is as follows: It is expected that 4 cavities for the “1<sup>st</sup> ILC module” will be produced in a Cornell-Industrial collaboration. The other 4 cavities will come from KEK. Once the cavities have passed the vertical dewar test at Cornell, they will be sent to JLab for Electropolishing (EP), vertical test and dressed. Once the test is successful, JLab will then mount the helium vessel, HPR and assemble flanges and the cold input coupler part to ready the cavity for horizontal test. At this point the cavity will be shipped to Fermilab for test in the Horizontal Test Dewar. A similar procedure will be followed for the KEK bare cavities. Oven treatment of the cavity at high temperature is still being discussed.

The new infrastructure needed at Cornell and JLab to get started in this way is minimal. Cornell has the necessary infrastructure except an 800 degree oven for hydrogen removal prior to final BCP. JLab has such an oven and cavities will be shipped to Jlab for this step. At JLab commissioning of their EP system is on going. It will be necessary to modify it for the TESLA cavity size and make other special modifications to their processing infrastructure. It is expected that these modifications will take place in FY05 and the tests of the EP process will begin on cavities supplied by DESY.

There is no 1.3 GHz Horizontal Test Dewar (HTD) in US so Fermilab will build this and use RF power from one of the “small modulators” installed in the Meson Hall. It is expected that fabrication of the HTD will start in FY05, and the small modulator will be available after the single Capture Cavity test at the end of FY05.

There also exists minimal SRF infrastructure at FNAL. If additional funds are available Fermilab should continue to develop its own SRF infrastructure. The present infrastructure Fermilab located at A0 consists of:

- Soft wall clean room of 16ft x 24 ft (entry area, ~200 sq ft class 100, ~100sq ft class10)
- Ultra Pure water system (1000 gallon storage)
- High Pressure Water Rinse system
- Miscellaneous equipment and ultra sound.

- Vertical dewar for 3.9 GHz test

Argonne and Fermilab have been collaborating on a chemistry facility located at ANL. This facility should be completed in FY05. Commissioning of the FNAL BCP system for 3.9 GHz cavities should take place in FY05 as well. Adaptation of the system for TESLA cavities should start in FY05, but initial treatment of TESLA cavities will probably not start until FY06.

On a longer scale it is hoped that with the help of KEK we will be able to implement a horizontal EP system at the Argonne facility. This then will give the US two such processing systems one at JLab and one at ANL. The cost of such a system may mean that it will be some time before it can be implemented. However it is important to have alternative systems for a reliable fast turnaround cavity development program.

The above discussion outlines a minimal program to get started with the assembly of two modules from cavities that have been processed and prepared elsewhere. The intension is that this model will continue with some modification for the fabrication of cavities and modules past the first couple. Fermilab should continue to develop its own SRF infrastructure and gain capability not only in module assembly but in cavity processing and testing as well.

The goals of this further infrastructure development are to:

- Continue infrastructure development to support the ongoing 3.9 GHz cavity development as well as TESLA cavities
- Bring to FNAL the ability to carry out an R&D program of process and test of ILC and Proton Driver cavities at a rate consistent with a relatively modest development program. (Of order 2 cavities/month). For instance this infrastructure should provide a reasonable and efficient turnaround time between test and reprocess and retesting of cavities
- Position FNAL so it (as well as JLab and Cornell) has the knowledge and expertise to direct and assist industry in the manufacturing, process, test, and assembly steps for industrialization and production.
- Provide at an adequate level, redundant processing capability to that existing at JLab so as to avoid schedule slips brought on by processing equipment failures or contamination leading to long duration recertification of the processing performance for achieving high gradient cavities.

## Phase 2 SRF Infrastructure

During Phase 2 many of the activities described above will continue with miscellaneous upgrades, improvements and ongoing operational expenses. Three major new investments are contemplated in Phase 2 that will give FNAL the capability learn and perform high performance cavity preparation and certification.

### Vertical Dewar

The vertical dewar CW RF test of bare cavities after fabrication is a key check of cavity gradient performance. Though a number of labs have this capability, it is important that Fermilab also obtains this ability so as to have rapid turnaround between chemical treatment and the resulting cavity performance. Fermilab designed and built two such dewar systems for the TESLA collaboration a number of years ago.

#### Chemical processing- ElectroPolishing

On a longer scale (Phase 2) it is hoped that with the help of KEK we will be able to implement a horizontal EP system at the Argonne facility. This will give the US two such processing systems one at JLab and one at ANL. The cost of such a system may mean that it will be some time before it can be implemented. However it is important to have alternative systems for a vigorous cavity development program. At some time such a system might become part of an industrial-lab cooperative activity.

#### Electron-Beam Welder

E-Beam welding is fundamental to cavity fabrication. The TESLA TDR cost estimate study recognized the possibility of major cost savings in cavity fabrication costs with a welder specifically designed for efficient cavity production. In the US there will need to be a dedicated welder(s) for ILC cavity production. Such a welder is not presently available and may make fabrication of cavities at a reasonable rate very difficult. Various laboratories have welders but they are in demand for a variety of projects. Industrial welding capability is very limited and it is extremely difficult to find dedicated machines.

#### Industrial Studies and Industrialization

It will be important to begin some level of industrial contact (beyond fabrication contracts) as soon as possible. This involvement should be at minimum include industrial studies, and participation with laboratories in module processing, test, and assembly. It should lead up to planning and prototyping of tooling etc for preproduction industrial activities. For ILC development this effort will clearly fall to the purview of the ILC coordination. However we include minimal funds in this proposal to indicate the importance of initiating the industrialization.

#### SRF Cryomodule Assembly Facility at MP9

The Fermilab cryomodule assembly facility will provide the infrastructure for the assembly of the SRF cryomodules. MP9 has no cryogenic capability and therefore it will only be used as a mechanical assembly facility. High power RF and beam testing of the completed cryomodules will be conducted at the Meson Lab test facility.

MP9 is intended to be an R&D production area. Based on DESY's experience, the first cryomodule is expected to take 3 to 4 months for assembly. The assembly of subsequent cryomodules is expected to take 3 to 4 weeks based on the experience from DESY for TESLA cryomodules and JLab for SNS cryomodules.

The Tesla Test Facility (Hall 3) layout at DESY was used as a reference while preparing this preliminary study for an SRF cryomodule assembly facility at MP9.

#### Assumptions:

The following assumptions were made in order to generate the production workflow for the SRF cryomodules at MP9:

SRF bare cavities are fabricated in industry. (Form/machine parts, electron beam welding)

- Cavities are processed (tuned for field flatness, baked, chemical etched, electro-polished, high pressure water rinsed) and vertical dewar tested. Then they are outfitted with a helium vessel, an input power coupler, and further dressed (tuner, magnetic shielding,) for the horizontal dewar test. It is assumed that these steps are not carried out at MP9. After passing this test the cavity with helium vessel and cold part of the input coupler is delivered sealed to the MP9 facility.
- The sealed cavities with cold input coupler are received at the MP9 facility for incorporation into cryomodules.

### **Production Work Flow of the 1.3 GHz Cryomodules:**

Given the assumptions listed in the above paragraph, the work flow steps to assemble a cryomodule can be generated, and the required infrastructure and tooling /fixtures associated with each step determined. The production steps and related infrastructure are shown in Figure 9.1 and summarized below as:

#### Receiving & Storing Dressed Cavities / Peripheral Parts:

Processed and dressed cavities will be stored at the Receiving & Storage area. The sealed cavity interiors have been backfilled with dry nitrogen or argon, while no special precautions other than bagging are taken with the cavity exteriors. The cavities are stored in their shipping containers on the storage racks until use. Peripheral components required for assembly of a cryomodule (such as warm coupler parts, tuners, magnetic shielding, vacuum vessel, cold mass components, and cryogenic piping, instrumentation, and alignment system components) will be stored in this area as well. An accurate inventory of all stored parts will be maintained, and a traveler system will assure proper material control procedures are followed for each kit of parts withdrawn from storage for the construction of a cryomodule. The footprint of the storage area is 60 ft x 60 ft. The area shall be clean for an industrial area. It will contain racks and shelves for storage of dressed cavities in their shipping containers, as well as peripheral parts kits. The area shall be situated to permit full semi-trailer truck access. The area shall have total crane coverage of at least 20-ton capacity.

#### Cavity String Assembly:

The sealed cavities are brought into the class 10 clean room assembly area and assembled into a cavity string in the Cavity String Assembly area. A string consists of 8 dressed 1.3 GHz cavities aligned and connected together. The cavities will be removed from their shipping containers, installed on a transport cart and washed to reduce the dust particle contamination on the outer surface prior to moving them into a Class 10 clean room. The Cavity String Assembly Class 10 clean room dimensions shall be at least 50 ft x 10 ft. It will have a cavity support, alignment and transportation rail fixture system.

#### Cryomodule Assembly:

The Cryomodule Assembly area is divided into two parts: (1) a Cold Mass Assembly area adjacent to the Cavity String Assembly clean room where the completed cavity string is integrated into the cold mass (defined as everything in the cryomodule except the cavity string and the vacuum vessel: including the cryogenic piping, radiation and super-insulation shields, cavity magnetic shields, alignment system, etc.) and (2) a Vacuum Vessel Assembly area where a large, cantilever fixture is used to install the cold mass/string assembly into the vacuum vessel. The footprints required are: 100 ft x 30 ft for the Cold Mass Assembly area and 160 ft x 10 ft for the Vacuum Vessel Assembly area.

A Tesla Cryomodule + lifting fixtures weigh over 8 tons, thus one needs at least 20 ton crane coverage for the whole Cryomodule Assembly area. MP9 has a 25 Ton crane.

#### Infrastructure and Tooling Setup at MP9:

The proposed layout of the Cryomodule Assembly Facility at MP9 can be seen in Figure 9.2. The major infrastructure needed for the assembly areas are clean rooms. One can summarize the needed major infrastructure as follows:

MP9 has a readily available production floor space a 25-ton crane is present in the building. We will need to purchase a variety of clean rooms and tooling fixtures for the Various areas.

## Work Flow at MP9

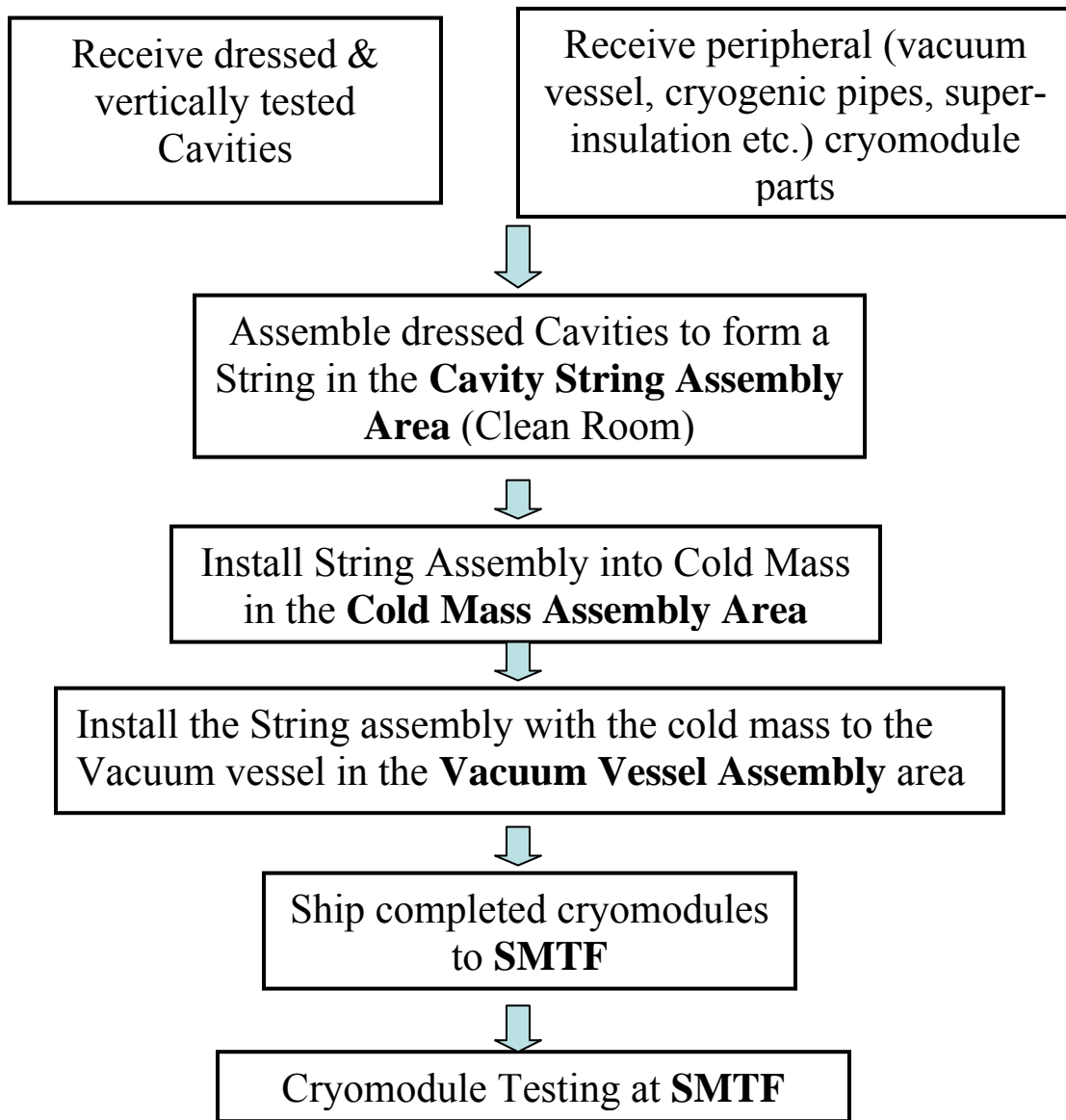
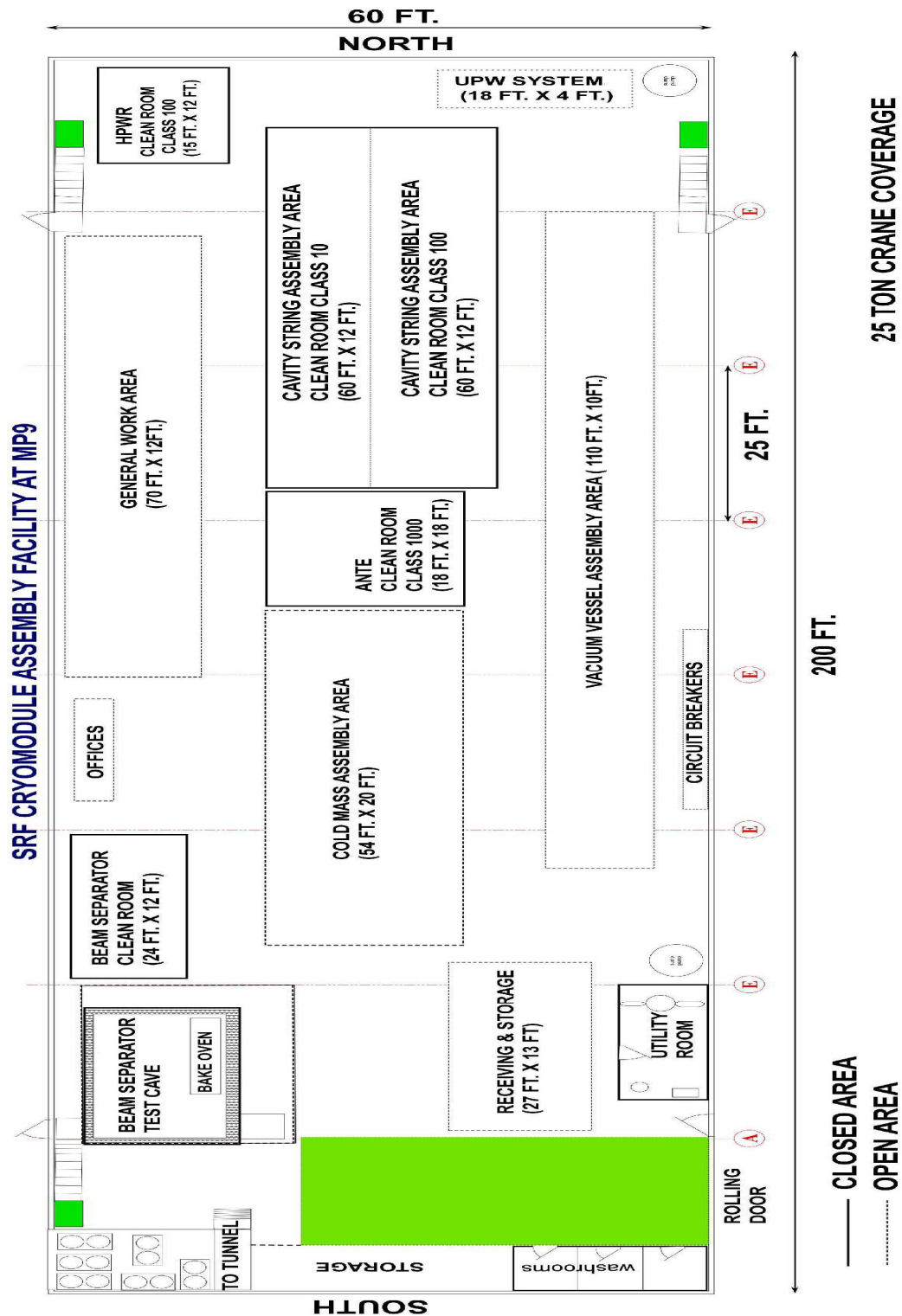


Figure 9.1 Flow of cavity to cryomodule at Fermilab MP9 Facility

### Summary:

The MP9 building will be used for the cryomodule assembly facility. Clean rooms and infrastructure are being procured. The [tooling and fixtures. designs are being provided by DESY.](#)



**Figure 9.2: Possible Layout of the Cryomodule Assembly Facility at MP9**

# 10. SMTF Facility

## a. Meson East Infrastructure

We describe in this chapter the plan, cost and schedule for the conventional and some technical infrastructure for the SMTF test area in the east beam lines of the Meson Hall. Conventional infrastructure includes space, shielding, utilities, such as electrical power, water and HVAC. The technical infrastructure included here is limited to the controls and communication backbone, and equipment for safety and radiation management. Other technical infrastructure, such as RF power sources and cryogenics are covered elsewhere in this proposal.

### i. Space in Meson Hall

The east side of Meson Hall, comprising two adjacent beam lines, ME and MP, has not been used for experiments for a number of years. The west side of Meson Hall is presently used for test beams, and the center beam line (MC) is in use for an active experiment. Present plans indicate that the MC beam line may be in use indefinitely, which restricts the space available for SMTF.

The appeal of Meson East rests on the availability of two important resources: a refrigerator capable of delivering at least 60 watts at 2 K exists and is operational, along with a cryogenic transfer line that extends from the refrigerator almost to the Meson East area; and the ME beam line is quite long and could be lengthened without major construction. In addition, a 20-ton crane covers the detector building, making installation and maintenance convenient and there is adequate installed power and water.

There are some disadvantages, however. The Meson East beam line is at grade level, which will require the installation of massive amounts of shielding when the beam lines reach full power capability. Moreover, in recent years Meson Hall has received little care and maintenance, and has become a storage area for magnets and no-longer-used experimental equipment. The roof is in some disrepair and there are places where there are significant water leaks during heavy rains. This problem will be moderated temporarily with judicious placement of plastic over the experimental area.

A general disassembly and cleanup is required to make the area useful. This activity is in progress and will be largely completed in FY2005 except for major items such as roof repair. Further improvements will extend into the out years, including roof repair, lighting repair and modernization, refurbishment of the HVAC and chiller systems, as well as general building maintenance activities.

#### Photo injector and 1.3 GHz Beam line Layout

After the cleanup and construction of the beam line caves are complete, the East area of Meson Hall will look as it does in Fig. 10.1. The East beam line starts in the South end of

the detector building with the photo injector, laser and beam analysis, and extends northward with the installation of 1.3 GHz superconducting modules. The plan shown is long enough to accept the first two long modules. The photo injector and the first large module are under crane coverage, but subsequent modules will have to be lowered into the cave onto dollies and wheeled to their proper position. The inside dimensions of the cave are 15' wide by 10.5' high and the center of the beam line is slightly offset to the east of center, resulting in a clear aisle for safety needs and module installation. The beam line can be extended by the use of shielding blocks. The steel "worms" may need to be enlarged at the downstream end of the beam lines.

The laser is in a moderately clean temperature-controlled room as shown in the Fig.10.2, which also shows the RF modulators and klystrons distributed along the west side of the shielding cave in convenient locations. The laser shed may be elevated so that it is not in the way of other equipment, but in any case its supports will be isolated from the building and supported on vibration dampers.

#### Proton Driver and $\beta < 1$ beam line

The ion source for the  $\beta < 1$  beam line is in the detector building under crane coverage, but the beam line in this case heads south into an existing shielded tunnel. This is possible because the length of this beam line is expected to be short, not exceeding 50 m when fully developed. Putting the beam into a tunnel reduces the amount of shielding that needs to be installed. The klystron is shown in the shielded tunnel, and the modulator is installed immediately outside the north end of the tunnel. The inside dimensions of the tunnel are roughly the same as the Meson East tunnel, as shown in Fig. 10.2.

#### CW test area

The CW test area will be in a separately shielded cave downstream of the ME beam line. It can use the  $\beta = 1$  beam for test that require beam. A separate electron gun source could also be installed, which will make test scheduling more convenient for all users. The major issue of the CW test facility is its use of cryogenics. One 1m long module is expected to require 40 watts at 2 K plus shield loads, so that it would be difficult to supply beam from the  $\beta = 1$  system simultaneously at 100 percent duty factor. Adequate tests can be performed, however, with a smaller duty factor so long as the pulse length is long compared to the cavity fill time. The RF power requirements for this system are small.

#### Horizontal test facility

A test facility that can have single modules of any kind connected to it for cryogenics and beam is also desired in this area. The refrigeration and power is adequate. It could be set up either near the  $\beta < 1$  beam line or even in the ME tunnel. This second location is convenient for connection to the refrigerator because it is close to the planned distribution box. RF power requirements are modest for this facility, and there are no beam requirements.

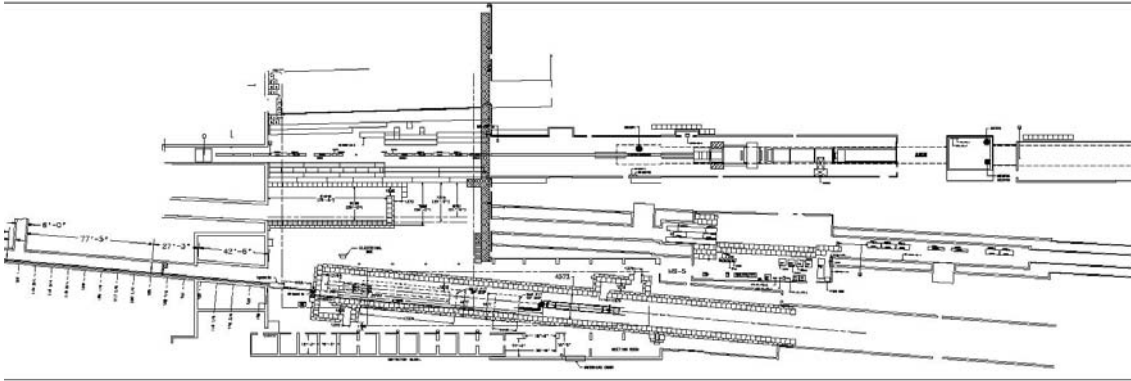


Fig. 10.1 Cleaned out Meson East area with shielding walls.

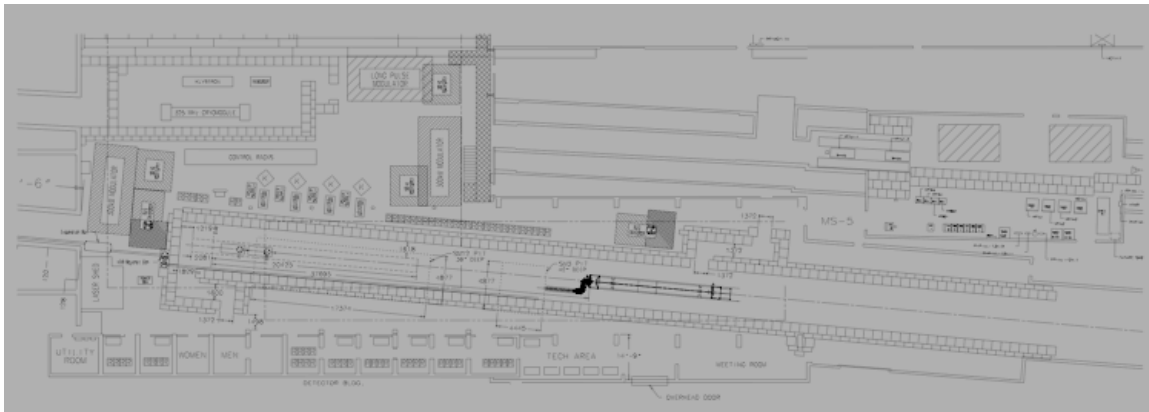


Fig 10.2 Meson East area with the addition of modules, modulators, klystrons and control racks. The CW test area (downstream of ILC) and the horizontal test facility in the ME tunnel are not shown.

## ii. Conventional Facilities in Meson Hall

### Power Distribution

The power distribution infrastructure must support the planned modulators and other systems. The power requirements for the  $\beta < 1$  and photo injector beam lines including the first two long modules are easily satisfied with one of the two available 1.5 MVA transformers at the southeast end of the detector building. The remaining two modules and the two large vacuum pump skids will be powered off another 1.5 MVA transformer conveniently located nearer the north end of the detector hall. One 500 KVA transformer at the south end of meson Hall will be shielded and will be more than adequate for the quiet power needs of the controls and low-level RF.

### Water Distribution

The total number of klystrons, solenoid magnets and modulators will require about 400 gpm of chilled LCW (max temperature  $< 35^{\circ}\text{C}$  at relatively low pressure, about 100 psi. The detector building LCW system can easily supply the amount needed at 200 psi, which will have to be regulated down in pressure and processed through a chiller capable of maintaining the temperature at the maximum load. Since all of the systems cannot operate simultaneously, the initial installation can be made with a smaller chiller.

### HVAC Installation

The requirements for heating, ventilation and air conditioning in the Hall are fairly modest. The occupied areas of the building are heated for comfort in the winter months, but air conditioning is supplied only where required, mostly for closed electronics racks with sensitive electronic equipment. We will upgrade the rooms along the East wall of the detector building for electronics and for office space. They will be temperature controlled. Fans may be required in the shielded caves to move the air and prevent moisture condensation.

## iii. Technical Infrastructure in Meson Hall

### Controls System Backbone

Rapid implementation of a controls system with characteristics that allow it to evolve quickly for our needs with minimal personnel effort is critical. An expert committee has been formed with representation from outside Fermilab to assess the requirements and make a recommendation of the system that best meets SMTF needs. This recommendation will be determined in the near future. Such a system should rely as much as possible on existing control systems and applications. By the end of FY 05 we will need the ability to control the cryogenic system and the RF modulator system for the capture cavity, and to interface to the low-level RF system and the modulator control-interlock interface. To set the scale of the control system that will be needed eventually, it is useful to note that the present TTF controls has approximately 40 VME crates and timer modules, 900 ADC channels, many of which are sampled at 1 or 9 MHz during the RF pulse.

### Safety Systems

The safety systems will be configured similarly to the Fermilab accelerator controls, but will be independent except for monitoring. The system has three major subsystems: radiation protection, high-power interlocks and oxygen deficiency hazard protection.

### Radiation Protection

Continuous radiation in the caves arises from four sources: x-rays from the cavities due to accelerated dark current; electrons from beam loss that will produce x-rays, gamma rays and neutrons, and, most important, neutrons from the beam stop. These neutrons have a significant backward component, making it necessary to shield even upstream of the

beam stop. Single events are not usually a problem because they are detected electronically and the beam shut off until the cause is fixed.

Radiation protection generally follows the rules and regulations of the Accelerator Division at Fermilab. The shielding is overlapping light concrete blocks to eliminate cracks. The design in Fig. 10.1 and 10.2 has 4.5 feet of light concrete in the walls and ceiling of the caves. The present allowable radiation inside the occupied areas the Meson Hall is 5 mrem at contact outside the shielding. Calculations are being done now to determine the amount of shielding necessary to meet that criterion.

### Electrical Hazards

The modulators and klystrons present potentially dangerous electrical hazards of high power, high voltage and large stored energy. Fortunately, Fermilab Accelerator Division has been dealing with similar hazards for many years and has developed effective protection systems and procedures to eliminate the dangers. This expertise will, of course, carry over to the Meson Hall installations.

### Oxygen Deficiency Hazards

Although the Meson Hall is large enough that it presents no oxygen deficiency hazards under any reasonable occurrence, the smaller volumes of the radiation caves do present possible hazards. The general procedure at Fermilab will be followed; training, oxygen concentration detectors in the space and on the personnel, air packs in enclosed spaces, and exhaust fans. Helium is probably not as much a problem as liquid nitrogen, since it can be easily vented with fans. Cold nitrogen, however, remains near the floor, and is more difficult to vent. In the longer term, nitrogen flow will probably need to be eliminated from tunnels and caves. This will probably await the Phase 3 refrigerator upgrade.

## **b. Cryogenics for SMTF at Fermilab**

The SMTF collaboration proposes to use the Cryogenic Test Facility (CTF) refrigerator system at Meson building at Fermilab to supply the initial helium for the SMTF. It is expected that this system will be capable of ~60 watts at 2K after its upgrade. This capacity will be sufficient for Phase 1 operation of SMTF, where we propose to share the cryogenic between different users. This facility will not support the full program of SMTF and a Helium plant with a capacity of ~>300 W at 2K is required.

Fermilab Cryogenic Department has started working in FY05 to develop the CTF facility for the Phase 1 operation of SMTF. This work will include:

- The installation of transfer lines from the refrigerator building to the Meson Hall
- Upgrade of CTF
- Provision for feed cans for the Capture Cavity Test (a main goal for FY05)
- Cryogenic controls

These upgrades will enable the collaboration to test components at 4K helium temperatures. Further upgrades are proposed for FY06 with a goal to operate an ILC 8, 9-cell cavities in a cryomodule in the Meson Hall at 2 K. This upgrade will require:

- Installation of a vacuum pumping system
- The construction of a large feed box and module feed and end cans
- Construction of the cryogenic transfer line
- Installation of associated cryogenic controls.

In FY05, the investigation of the best way to proceed with a larger 2K cryoplant is being pursued. One of the two possibilities is to try to use parts of the SSC system presently at Argonne National Laboratory. A second possibility is to procure a modern system specifically built for 2K SRF operation similar to that at Rossendorf (Germany). This new system is expected to take about 2 years for the procurement, fabrication and installation. This proposal request funds in FY06 for a new cryogenic plant with a capacity of ~300 Watts at 2K. As described in the earlier sections of the proposal this capacity is required to support cryomodules and test areas. Even at this capacity the different accelerator groups would be required to share the cryogenics.

Beyond providing cryogenic equipment for a single TESLA cryomodule (in the ILC string area) by the end of 06, additional cryogenic infrastructure is needed for the following components:

1. The photo injector.
2. Upgrading to four cryomodules.
3. Providing for test cryostats, e.g. Horizontal and Vertical Test Dewars.
4. Providing for other string areas, e.g. Proton Driver and CW.
5. Long term upgrade of the injector to a 8 cavity TESLA module with a 4 cavity 3.9 GHz module.

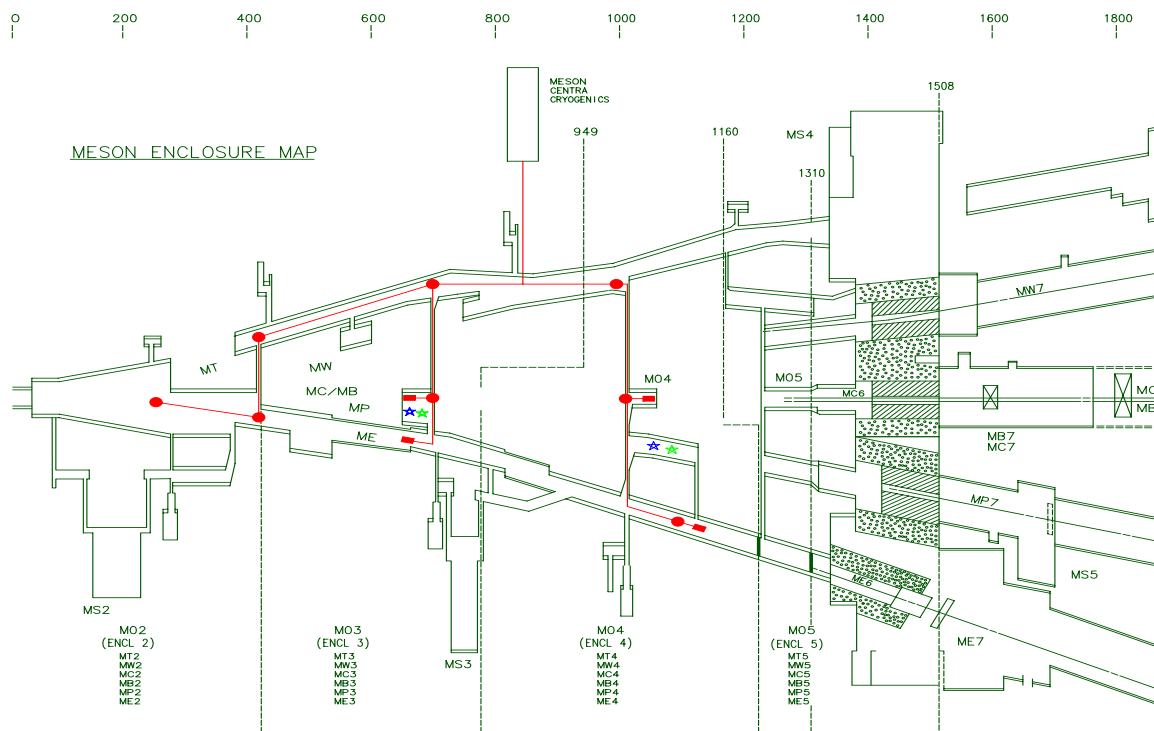
1) The first stage of the injector will include two 1.3 GHz Tesla SRF cavities (CapCav #1 and #2) and two 3.9 GHz SRF cavities (one accelerating mode and one deflecting mode cavity). These will require single cavity feed boxes similar to that built for the first Capture Cavity test in FY05.

2) The module feed box and feed and end cans planned for fabrication in FY06 should be adequate to support a four module system. However there will need to be some modifications when four modules are installed.

3) Part of the development of SRF infrastructure at Fermilab will be development of Horizontal and Vertical Test Dewars. These will be located at Meson Hall and connected to the cryogenic system. Construction and commissioning of this system in early FY06 will be critical for first cavity tests and preparation for module string assembly. Cryogenic support of the test dewar will be similar to that needed for the CapCav test in FY05 and will use much of the same equipment.

4) Provide CW for the proton and CW area. Additional modifications to the feed box and feed end can will needed to support at 1.8K.

5) For the very long term an upgrade of the injector, similar to that that has just taken place at DESY for TTFII, has been proposed. This upgrade would incorporate an 8 cavity TESLA module followed by a 4 cavity 3.9 GHz module as the main accelerating elements and linearizing of the injector beam. This installation would require module feed and end caps like those built for the 1<sup>st</sup> TESLA module and/or bypass lines to connect to the module string.



**Figure 10.3 Meson Enclosure Map and Present Cryogenic Transfer Line Location**

### Meson Area

The Meson beam line enclosures are shown in Figure 10.3. Currently Meson enclosure is used for Meson Test Beam Facility (MTBF) and E907. The MTBF is located in the  $M_{Test}$  beam line and E907 in the  $M_{Center}$  beam line. MTBF enables experimenters who are planning experiments to test their detectors in an active beam line and also permits detectors for other types of research (cosmic rays, etc.) to be calibrated. E907 –The Main Injector Particle Production (MIPP) Experiment will measure the production of particles by the 120 GeV Main Injector proton beam for the NuMI project targeting.

### Cryogenics

Cryogenic Test Facility (CTF), formerly the Meson Central Cryogenics (MCC), located on the west side of the Meson beam line, can provide cryogenics for a cryomodule test. CTF houses three (3) Tevatron satellite refrigerators capable of producing a total of 1,500 W at 4.5K. Cryogenic transfer line from the CTF is available in M02, M03 and M04 enclosures, formerly servicing superconducting bending magnets in various portions of the East, Center and West beam lines. This cryogenic system can be modified to support test operation through Phase 2 (Table 2.) Emphasis will be placed on establishing 4.5K helium and LN<sub>2</sub> from the CTF to the Meson Detector Building (MDB) for use in a single cryomodule test utilizing a vacuum pumping system to achieve super fluid helium. For Phase 2, a new cryogenic plant is required. Design, construction, installation and commissioning of a new refrigerator will require a minimum of two years from the point the contract is let.

In order to satisfy a remote super fluid helium load, the CTF refrigerators will be operating in a liquefier mode. Operation in this mode is inherently less reliable. It is more demanding on expander and heat exchanger performance. Helium impurity degrades the expander and heat exchanger performance, thus is detrimental to the reliability and capacity of the system.

The transfer line and header connections to the refrigeration system have been removed in order to perform cryogenic testing within CTF while maintaining the Meson enclosures ODH Class 0. In order to reactivate the transfer line, a new bayonet would have to be designed and built. There is a known design flaw in some of the expansion cans used in the Meson transfer line system. Prior to reactivating the transfer line, all expansion cans of this type would need to be checked and repaired. Transfer line, helium and nitrogen suction header extensions currently leading to M02 and M03 will be isolated from the rest of the tunnel system.

The transfer line in M<sub>East</sub> will need to be extended about 300' from ME4 to MDB. An appropriate transfer line expansion box will need to be installed in the extension. The existing ME4 bayonet would be moved to the MDB. The helium and nitrogen suction headers will need to be extended by the same distance. When this work is completed, it will enable 4.5K helium and 80K nitrogen to be delivered to the MDB.

Part of the 4.5K stream will be used in the production of superfluid helium. The remainder of the 4.5K flow will be used to satisfy 5-8K heat shield loads in the cryomodules and to maintain stability in the CTF/MDB cryogenic transfer line. For convenience, the 40-80K shield loads in the cryomodules will be cooled using 80K LN<sub>2</sub>. From this point, cryogens can be distributed to SRF test area(s).

Distribution of cryogens within a test cave will require a bayonet can, transfer line, feed can and end cap. Low pressure helium from the cryomodule will be warmed to room temperature in a header leading to the vacuum pumping system. It is imperative that the subatmospheric portion of the system remains leak tight for reliable cryogenic system operation. The vacuum pumping system requires an oil removal system to ensure the prevention of oil migration. Care will need to be taken to ensure that inherent vibration of

the positive displacement vacuum pumps will be isolated in order to not impact SRF performance.

The control system used at MCC during the last Fixed Target run was removed for a cryogenic controls upgrade at CDF. Since then, new controls have been installed and the system is now operational. The facility is currently being operated for various Tevatron cold compressor tests related to Collider Run II maintenance and reliability. Future test plans include a versatile test cryostat to investigate hydrodynamic and thermal properties of single and two phase He I and He II. To perform tests in He II, a small vacuum pumping system has been installed capable of cooling loads of about 10 watts down to 1.8 K.

A new local distributed cryogenic controls system is required to operate the cryogenic distribution and vacuum pumping systems. This controls system must be integrated to the existing CTF refrigerator controls system. Cryogenic instrumentation required for the distribution, vacuum pumping and cryomodule systems will feed into this controls system.

### Heat Load

Heat load of a single 9 cell TESLA cryomodule with a quadrupole at  $E = 23.4$  MV/m,  $Q = 1 \times 10^{10}$  and 5 Hz repetition rate is presented in the Table 10.1 below.

It is desirable to operate the TESLA cryomodules with a gradient of 35 MV/m in the SMTF. This adds considerably to the dynamic heat load. A summary of a first pass estimated heat load at the three temperature levels for Phase 0, 1, 2 and 3 are given in Table 10.2. Cavity RF loads were scaled from the TESLA Technical Design Report by

	$E_{acc}$ [MV/m]		Q		Rep Rate [Hz]	
	23.4		1.00E+10		5	
TESLA 9 cell module w/ Quad	2K load [W]		5/8 K load, [W]		40/80 K load, [W]	
	static	dynamic	static	dynamic	static	dynamic
RF load	-	4.95	-	-	-	-
Radiation	-	-	1.95	-	44.99	-
Supports	0.60	-	2.40	-	6.00	-
Input coupler	0.76	0.14	2.05	1.19	21.48	59.40
HOM coupler (cable)	0.01	0.27	0.40	2.66	2.55	13.22
HOM absorber	0.14	0.02	3.13	0.77	- 3.27	15.27
Beam tube bellows (12)	-	0.24	-	-	-	-
Current leads	0.10	0.01	-	-	13.00	5.00
HOM to structure	-	1.68	-	-	-	-
Coax cable (4)	0.01	-	0.03	-	0.08	-
Instrumentation taps	0.05	-	0.54	-	2.82	-
Diagnostic cable	0.07	-	0.82	-	2.48	-
Subtotal	1.74	7.31	11.32	4.62	90.13	92.89
<b>Total</b>	<b>9</b>		<b>16</b>		<b>183</b>	

**Table 10.1 TESLA 8 Cavity Cryomodule Heat Load Estimate (courtesy S. Wolff)**

the cavity Q, RF pulse length and square of the gradient ratios. TESLA TDR and A0 operating experience is used for the static heat load estimates. Further detailed understanding of other dynamic loads within the cryomodule is warranted. For the purpose of this study, an uncertainty factor of 1.3 is used to compensate unknown loads. The loads presented in Table 10.2 define the applicability of CTF as Phase 0 and 1 at a 5 Hz rep rate and Phase 2 at a 1 Hz rep rate. A new cryogenic system is required to support Phase 2 with injector at 5 Hz and Phase 3, as represented by the dotted line.

**Table 10.2 Phased SMTF Heat Load Estimates**

		Single Cavity Module				Multi Cavity CryoModule								
		Accelerating Gradient, [MV/m]												
Phase	Rep rate	12.5	30	15	5	35	35	35	35	35	15	Capacity Required*		
		Cap Cav		3.9 GHz		8 Cavity Module					4 Cav	2K	5K	80K
	[Hz]	#1	#2	Acc	Tran	#1	#3	#4	#5	#6	3.9 GHz	[watts]	[watts]	[watts]
0	5		X									9	11	73
I	5					X						36	29	533
Inj A	5	X	X			X						52	51	666
Inj B	5	X	X	X	X	X						59	74	812
II	1	X	X	X	X	X	X					37	70	478
	5					X	X					73	58	1065
<hr/>														
	5	X	X	X	X	X	X					95	103	1345
III	5					X	X	X	X			145	116	2130
	1	X	X	X	X	X	X	X	X			60	110	834
	5	X	X	X	X	X	X	X	X			167	161	2410
Inj C	5				X	X	X	X	X	X	X	198	201	3029

\* - Capacity required is based on the estimated heat load for  $Q = 5 \times 10^9$  and is inflated by 30%

# 11. Generic Accelerator Physics

This section describes three separate efforts that we expect will take advantage of the SMTF. We anticipate that as questions arise from the R&D progress of the SMTF collaboration we will use the facility to understand and answer them. Three areas of ongoing research which are related to the SMTF mission are described below. This research will provide a training ground for future accelerator physicists and engineers.

## a. Potential applications of an electron beam at SMTF: R&D for ILC and advanced accelerator physics

The availability of a facility providing electron beam with energies ranging from 40-50 MeV (injector phase A) up to 1 GeV (final stage of SMTF) will foster an extensive accelerator physics program.

In the context of ILC and current linac-based light source proposals, an electron beam (with possible high average current), could be used to characterize the superconducting cavities and module: from measuring the accelerating gradient of individual cavities to studying their intricate beam dynamics properties (focusing properties, high order mode wake field excitations, short range wakefield study, etc...). The facility could also test the concept of flat beam at higher energy than the experiment being done at 16 MeV at FNPL. Such an experiment, if as successful as predicted<sup>19</sup>, could have significant impact on the design of the electron damping ring. The flat beam transform, installed downstream of one accelerator module, could also be viewed as a full scale demonstration of LUX flat beam generation scheme<sup>20</sup>. Finally a 1 GeV electron beam facility will provide, after optimization, beam parameters (normalized emittance, bunch length) identical to those that would be achieved at 5 GeV by the ILC injector. Thus the facility could serve as a test stand for optimizing the injector beam parameters and developing the proper beam instrumentation needed to diagnose the beam.

At a latter stage, our foreseen design does not preclude, for experimental purpose, the exchange of the rf-gun with a polarized gun (either RF or DC) for production of polarized electron beam.

At energies above 500 MeV, the electron beam can also be used to produce positrons (by impinging a tungsten target for instance), a lot of beam dynamics aspects of the positron source, especially the capture section including the adiabatic matching device, could be tested and optimized at SMTF.

Finally if the accelerator is available a priori to the construction of the European X-ray FEL, there are aspects of the X-FEL design that could be tested at SMTF (for instance the

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<sup>19</sup> P.Piot, presentation at the 1<sup>st</sup> ILC workshop, slides available at [http://lcdev.kek.jp/ILCWS/Talks/15wg3-30-WG3-30\\_Electron\\_Discussion\\_Piot.pdf](http://lcdev.kek.jp/ILCWS/Talks/15wg3-30-WG3-30_Electron_Discussion_Piot.pdf) (November 2004)

<sup>20</sup> S. Lidia, in *Proceedings of the 2004 European Particle Accelerator Conference*, Lucerne Switzerland, p. 476 (2004)

rf-gun in the XFEL is operated at higher gradient than in TTF VUV FEL and this has impact on the distance between the rf-gun and 1<sup>st</sup> accelerating module location)

High energy electron beam will also provide a tool for testing new ideas or concepts, for instance flat beam propagated very close to a grating<sup>21</sup>, or between two gratings can provide intense pulses via the Smith-Purcell effect, such an idea is presently thought to be the path toward ultra-short wavelength compact FELs utilizing the so-called image charge undulator<sup>22</sup>. In addition the advanced accelerator physics program currently pursued at FNPL (plasma-wake field acceleration, laser-based acceleration, etc...) could be extended (for instance at 100 MeV the vacuum laser-based acceleration is possible without the use of a medium to slow the laser phase velocity). We expect R&D on instrumentation to be a large activity at SMTF, for instance the recent use of electro-optical sampling in beam diagnostics has open new possibilities for measuring beam distribution with 100 femtosecond resolution<sup>23</sup>. This technique could be extended at SMTF. On another hand beam halo detectors being developed for high intensity proton linac could be tested with electron beam. There is finally a new class of accelerator-based astrophysics experiments being considered<sup>24</sup>, this type of experiments could also be envisioned at SMTF. We should finally mention that there is a strong synergy between advanced accelerator physics and optical techniques, the SMTF collaboration should therefore undertake the development of a laser laboratory (operating and upgrading the photocathode drive laser and also a ultra-short infrared laser capable of providing 100 fs pulses).

As briefly outlined in this Section, we expect the opportunity of having a high energy electron beam to drive an extensive program of accelerator and beam physics. This sort of program and operation of the SMTF with beam is important for training of young accelerator scientists and engineers.

## b. SRF Materials R&D at SMTF

The SMTF activity will also include materials R&D to support the gradient and Q goals of SMTF, as well as to pursue ultimate gradients and lower cost of SRF linear accelerators. There are many material R&D topics worthy of further investment. The following list, without claiming to be exhaustive, identifies the most important among them. There are also several superconducting materials that can be used for SRF cavities. It is clear, however, that niobium will most likely be the prime candidate material for a large-scale linear collider. Therefore the following topics are mostly related to niobium.

1. Improving the understanding of the effect of the cavity processing steps such as polishing and baking on the chemical surface composition and its impact on the RF surface resistance at high fields;

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<sup>21</sup> K.-J. Kim and S. B. Song, *Nucl. Instr. Meth.* **A475**, p. 158 (2001)

<sup>22</sup> Y. Zhang, Ya. Derbenev, J.R. Boyce, and R. Li., in *Proceedings of the 2003 Particle Accelerator Conference, Portland OR*, IEEE Publishing, Piscataway, New Jersey, p. 941 (2003)

<sup>23</sup> Result achieved by the SPPS collaboration at SLAC (2004)

<sup>24</sup> See for instance review by J.S.T. Ng, <http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-r-630-ch40.pdf>

2. Understanding and measuring the critical RF field;
3. Measuring the superconductor property profile (e.g. gap energy) across the RF field penetration layer;
4. Improving the understanding of the dynamics of RF vortex penetration into the superconductor, with particular emphasis of the effects of grain boundaries (and grain boundary chemistry) and surface topology;
5. Understanding and improving the high electric field breakdown and field emission thresholds;
6. Understand and improve the basic material properties, such as thermal conductivity and Kapitza interface resistance;
7. Surface analysis measurements with surface analytical tools such as, SEM, SAM, XPS, and SIMS as warranted to improve understanding of the composition and the physics of RF penetration layer.
8. Continue to develop Cu-Nb composite cavity fabrication technologies, such as based on co-extrusion or thin films, and the associated knowledge of the material properties (such as the mechanical properties);

All national laboratories and universities participating in this proposal conduct some basic SRF along with material R&D. The collaborative activities of SMTF will be an excellent forum for dissemination of ideas and results. Most of the listed issues are being addressed. Extensive surface analysis is being carried out at JLab Cornell and to further our understanding of the physics of the RF penetration depth (item 7). RF critical field measurements are being continued as for example on niobium at 11.4 GHz by a SNS/SLAC/JLab collaboration under R. Campisi (item 2 in list). Other examples are the plasma sputtering efforts at JLab/Cornell collaboration (item 7) or the effort at MSU to measure the thermal properties of high purity niobium for SRF (item 6). Fermilab has just recently launched two potentially promising collaborations with the UW and NU. The collaboration with the UW aims to improve the understanding of the dynamics of RF vortex penetration into the superconductor, item 2 in the above list. The collaboration with NU was established to investigate the chemical properties of the high purity niobium used in the cavity fabrication with 3D atomic probe microcopy (3DAP). This activity therefore addresses item 1 in the above list. 3DAP will also be used to investigate field emission in SRF cavities (item 5), a collaboration between NU and ANL. Other material related activities that practically all SRF laboratories engage in are (electron-) microscopy, surface roughness analysis, RRR measurements and eddy current scanning. Fermilab, for instance, is developing a host cavity to measure the properties of small samples prepared by different methods. The aim is to rapidly measure a large number of samples prepared by the same method to obtain good statistics.

In short, the SMTF effort will bring together a large number of world leading experts to address basic issues in SRF performance.

## 12. Cost and Schedule

In this section we present the cost and schedule for the SMTF. The cost is shown in Tables 12.1-12.7 rolled up to the one-level of WBS (from 3-5 levels). The infrastructure and ILC costs have been based on Fermilab experience and consultation with DESY on costs for TTF. The proton driver costs have been based on Fermilab experience and costs for SNS, RIA R&D, and experience with DESY cryomodule costs. The requested budget is shown for FY05-FY12. The budget has been divided into the SMTF infrastructure part, the component parts for the four proposed areas and the operation of the facility. The operations budget includes support for training young scientists and engineers, who will be essential for the next generation of accelerators. The M&S costs are calculated for the ILC for FY05-FY10, the injector for FY05-FY11, for CW FY06-FY08, for RIA FY07-FY08, and for the PD FY05-FY09. The budget estimates are \$23M for the infrastructure, \$18M for the International Linear Collider, \$6M for Injector Upgrades, \$16M for Proton Driver, \$2M for Rare Isotope Accelerator cavity testing, \$9M for CW cavity research and finally, \$22M for operations over a 8 year period. The requested M&S budget is \$96M. Contingency has been estimated to be 10% on the operational costs and 25% on equipment costs for a total estimated contingency of \$20M. The total requested M&S funds are \$116M. The estimated FTE-years needed over all areas and operations is ~1000 over 8 years.

The total budget includes the RIA hardware budget and FTE requested from SMTF at Fermilab. The table also includes RIA project specific budget and FTE estimates. The RIA specific cost such as the cost of cryomodules etc is not included in the SMTF total budget.

### SMTF Proposal: Budgetary & Personnel Estimates Summary

WBS	Description	Total with Contingency	Totals		FY05		FY06		FY07		FY08		FY09		FY10		FY11		FY12		
			k\$	FTE-y	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	
Totals			\$ 117,156	\$ 96,404	995	\$ 8,086	100	\$ 23,243	203	\$ 21,648	143	\$ 16,869	144	\$ 12,459	112	\$ 5,804	97	\$ 6,720	105	\$ 1,575	91
1,2,3,&10	SMTF	\$ 54,143	\$ 45,995	771	\$ 3,148	54	\$ 9,638	140	\$ 10,359	105	\$ 6,260	106	\$ 5,905	93	\$ 4,555	91	\$ 4,555	91	\$ 1,575	91	
4&5	ILC	\$ 22,055	\$ 17,644	80	\$ 2,518	14	\$ 2,710	18	\$ 2,444	12	\$ 4,879	14	\$ 4,044	14	\$ 849	6	\$ 200	2	\$ -	0	
6	Injector	\$ 7,524	\$ 6,019	30	\$ 120	0	\$ 1,114	13	\$ 1,310	0	\$ 710	5	\$ 400	0	\$ 400	0	\$ 1,965	12	\$ -	0	
7	CW	\$ 10,813	\$ 8,650	26	\$ -	0	\$ 3,000	11	\$ 3,450	10	\$ 2,200	6	\$ -	0	\$ -	0	\$ -	0	\$ -	0	
8	RIA	\$ 2,463	\$ 1,970	7	\$ -	0	\$ -	1	\$ 850	3	\$ 1,120	3	\$ -	0	\$ -	0	\$ -	0	\$ -	0	
9	Proton	\$ 20,158																			
Driver			\$ 16,126	88	\$ 2,300	32	\$ 6,781	22	\$ 3,235	16	\$ 1,700	13	\$ 2,110	5	\$ -	0	\$ -	0	\$ -	0	

Table 12.1 Summary of the total SMTF Budget and FTE estimate

## SMTF Proposal: Budgetary & Personnel Estimates

WBS	Description	SMTF Phase	Totals with Contingency		Totals		FY05		FY06		FY07		FY08		FY09		FY10		FY11		FY12	
			k\$	FTE-y	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE
SMTF Totals																						
			\$ 54,143	\$ 45,995	771	\$ 3,148	54	\$ 9,638	140	\$10,359	105	\$ 6,260	106	\$ 5,905	93	\$ 4,555	91	\$ 4,555	91	\$ 1,575	91	
1	Cryogenic Infrastructure		\$	13,136	\$ 10,509	66	\$ 797	14	\$ 4,506	26	\$ 5,006	13	\$ 180	9	\$ 5	1	\$ 5	1	\$ 5	1	\$ 5	1
1.1	Initial ILC Cryogenics			\$ 2,245		28	\$ 367	14	\$ 1,819	13	\$ 34	2	\$ 5	0	\$ 5	0	\$ 5	0	\$ 5	0	\$ 5	0
1.2	New Refrigerator 300W@2K	II+		\$ 6,480		11	\$ 30	0	\$ 2,000	1	\$ 4,450	5	\$ -	1	\$ -	1	\$ -	1	\$ -	1	\$ -	1
1.3	Test station cryogenics			\$ 1,010		16	\$ 400	0	\$ 435	8	\$ -	0	\$ 175	8	\$ -	0	\$ -	0	\$ -	0	\$ -	0
1.4	SMTF PD Cave System			\$ 774		11	\$ -	0	\$ 252	4	\$ 522	7	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0
2	Meson Hall General Infrastructure		\$	5,676	\$ 4,541	28	\$ 486	4	\$ 1,222	9	\$ 1,153	3	\$ 480	3	\$ 300	3	\$ 400	2	\$ 400	2	\$ 100	2
3	SRF Infrastructure		\$	10,756	\$ 8,605	56	\$ 1,325	16	\$ 1,360	20	\$ 420	3	\$ 1,970	8	\$ 1,970	3	\$ 520	2	\$ 520	2	\$ 520	2
3.1	Preparation & Processing			\$ 5,635		22	\$ 345	7	\$ 570	7	\$ 220	1	\$ 1,770	6	\$ 1,770	1	\$ 320	0	\$ 320	0	\$ 320	0
3.2	Cavity Tooling & Fixturing			\$ 60		3	\$ 30	2	\$ 30	2												
3.3	Cryomodule Assembly Facility (MPG)			\$ 1,310		15	\$ 750	6	\$ 560	9	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0
3.4	SRF Materials Research			\$ 1,600		16	\$ 200	2	\$ 200	2	\$ 200	2	\$ 200	2	\$ 200	2	\$ 200	2	\$ 200	2	\$ 200	2
10	General Operations		\$	24,574	\$ 22,340	622	\$ 540	20	\$ 2,550	86	\$ 3,780	86	\$ 3,630	86	\$ 3,630	86	\$ 3,630	86	\$ 3,630	86	\$ 950	86

Table 12.2 Summary of the SMTF Infrastructure and Operation Budget and FTE.

## SMTF Proposal: Budgetary & Personnel Estimates for ILC

WBS	Description	SMTF Phase	Totals with Contingency k\$		Totals		FY05		FY06		FY07		FY08		FY09		FY10		FY11		FY12	
			k\$	FTE-y	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE
ILC Totals																						
			\$	22,055	\$ 17,644	80	\$ 2,518	14	\$ 2,710	18	\$ 2,444	12	\$ 4,879	14	\$ 4,044	14	\$ 849	6	\$ 200	2	\$ -	0.00
4	ILC Cavities & Modules		\$	11,461	\$ 9,169	25	\$ 2,018	4	\$ 2,100	8	\$ 1,689	4	\$ 1,629	4	\$ 1,419	3	\$ 314	2	\$ -	0	\$ -	0.00
4.1	DESY Module	I		\$ 50		2	\$ -	0	\$ (1,051)	2	\$ 50	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0.00
4.2	First U.S. Module	I-II		\$ 2,918		13	\$ 2,018	4	\$ 900	4	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0.00
4.3	Second U.S. Module	III		\$ 1,839		5	\$ -	0	\$ 1,200	2	\$ 639	2	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0.00
4.4	Third U.S. Module	III		\$ 1,629		4	\$ -	0	\$ -	0	\$ 1,000	2	\$ 629	2	\$ -	0	\$ -	0	\$ -	0	\$ -	0.00
4.5	Fourth U.S. Module	III		\$ 1,419		4	\$ -	0	\$ -	0	\$ -	0	\$ 1,000	2	\$ 419	2	\$ -	0	\$ -	0	\$ -	0.00
4.6	Fifth U.S. Module	III		\$ 1,314		3	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ 1,000	2	\$ 314	2	\$ -	0	\$ -	0.00
5	ILC Modulators, Klystrons & RF		\$	10,594	\$ 8,475	55	\$ 500	10	\$ 610	10	\$ 755	8	\$ 3,250	11	\$ 2,625	11	\$ 535	4	\$ 200	2	\$ -	0.00
5.1	SMTF Phase 1	I		\$ 1,010		18	\$ 500	10	\$ 510	8	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0.00
5.2	SMTF Phase 2	II		\$ 2,235		11	\$ -	0	\$ -	0	\$ 355	4	\$ 1,880	8	\$ -	0	\$ -	0	\$ -	0	\$ -	0.00
5.3	SMTF Phase 3	III		\$ 2,260		10	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ 1,925	8	\$ 335	2	\$ -	0	\$ -	0.00
5.4	Other			\$ 300		2	\$ -	0	\$ -	0	\$ 300	2	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0.00
5.5	Spare Klystrons			\$ 670		0	\$ -	0	\$ -	0	\$ -	0	\$ 670	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0.00
5.6	Industrialization			\$ 2,000		14	\$ -	0	\$ 100	2	\$ 100	2	\$ 700	3	\$ 700	3	\$ 200	2	\$ 200	2	\$ -	0.00

Table 12.3 Summary of the ILC Hardware Budget and FTE.

## SMTF Proposal: Budgetary & Personnel Estimates for Proton Driver

WBS	Description	SMTF Phase	Total with Contingency k\$	Totals		FY05		FY06		FY07		FY08		FY09	
				k\$	FTE-y	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE
9	Proton Driver		\$ 20,158	\$ 16,126	88	\$ 2,300	32	\$ 6,781	22	\$ 3,235	16	\$ 1,700	13	\$ 2,110	5
9.1	H - Warm Front End			\$ 5,633	26	\$ 600	12	\$ 3,763	10	\$ 970	2	\$ 300	2		
9.2	Beta<1 single spoke resonator cryomodules			\$ 4,100	15	\$ 300	2	\$ 1,300	2	\$ 1,500	7	\$ 1,000	4		
9.3	325 MHz RF comp. and phase shifter			\$ 1,053	4	\$ 570	1	\$ 483			1		1		1
9.4	325 MHz Modulator			\$ 500	6	\$ 500	6								
9.5	325 MHz RF Comp. & Phase Shifr			\$ 725	8		4	\$ 515	4					\$ 210	
9.6	325 MHz LLRF (assume shared effort)			\$ 300	8		2	\$ 100	2	\$ 100	2	\$ 100	2		
9.7	Beta<1, 1.3GHz Cryomodule			\$ 2,500	10			\$ 150		\$ 150	2	\$ 300	4	\$ 1,900	4
9.8	1300 MHz RF Comp. & Phase Shifr			\$ 1,315	11	\$ 330	5	\$ 470	4	\$ 515	2				

Table 12.4 Summary of the Proton Driver Hardware Budget and FTE.

## SMTF Proposal: Budgetary & Personnel Estimates for CW

WBS	Description	SMTF Phase	SMTF with Contingency k\$	Totals		FY05		FY06		FY07		FY08	
				k\$	FTE-y	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE
7	CW Facilities		\$ 10,813	\$ 8,650	26	\$ -	0.00	\$ 3,000	11	\$ 3,450	9.50	\$ 2,200	6
7.1	Accelerating cavities			\$ 4,500	14	\$ -	0.00	\$ 2,000	5	\$ 1,400	5.75	\$ 1,100	3
7.2	Deflecting Cavities			\$ 4,150	12	\$ -	0.00	\$ 1,000	6	\$ 2,050	3.75	\$ 1,100	3

Table 12.5 Summary of the CW Hardware Budget and FTE

## SMTF Proposal: Budgetary & Personnel Estimates for RIA

WBS	Description	SMTF Phase	SMTF with Contingency k\$	Totals		FY05		FY06		FY07		FY08		FY09		FY10		FY11		FY12	
				k\$	FTE-y	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE
8	RIA		\$ 2,463	\$ 1,970	7	\$ .	0.00	\$ .	1	\$ 850	3	\$ 1,120	3	\$ .	0.00	\$ .	0	\$ .	0	\$ .	0
8.1	Infrastructure			\$ 1,970	7	\$ .	0.00	\$ .	1	\$ 850	3	\$ 1,120	3	\$ .	0.00	\$ .	0	\$ .	0	\$ .	0
8.2	Project activities (RIA budget items)			\$ 5,000	120	\$ .	0.00	\$ .	1	\$ 1,700	8	\$ 2,450	16	\$ 300	30.00	\$ 350	35	\$ 300	30	\$ .	0

Table 12.6 Summary of the RIA Hardware Budget and FTE requested from SMTF. The table also include RIA project specific Budget and FTE estimates that are not included in SMTF total.

## SMTF Proposal: Budgetary & Personnel Estimates for Injector and Beamline

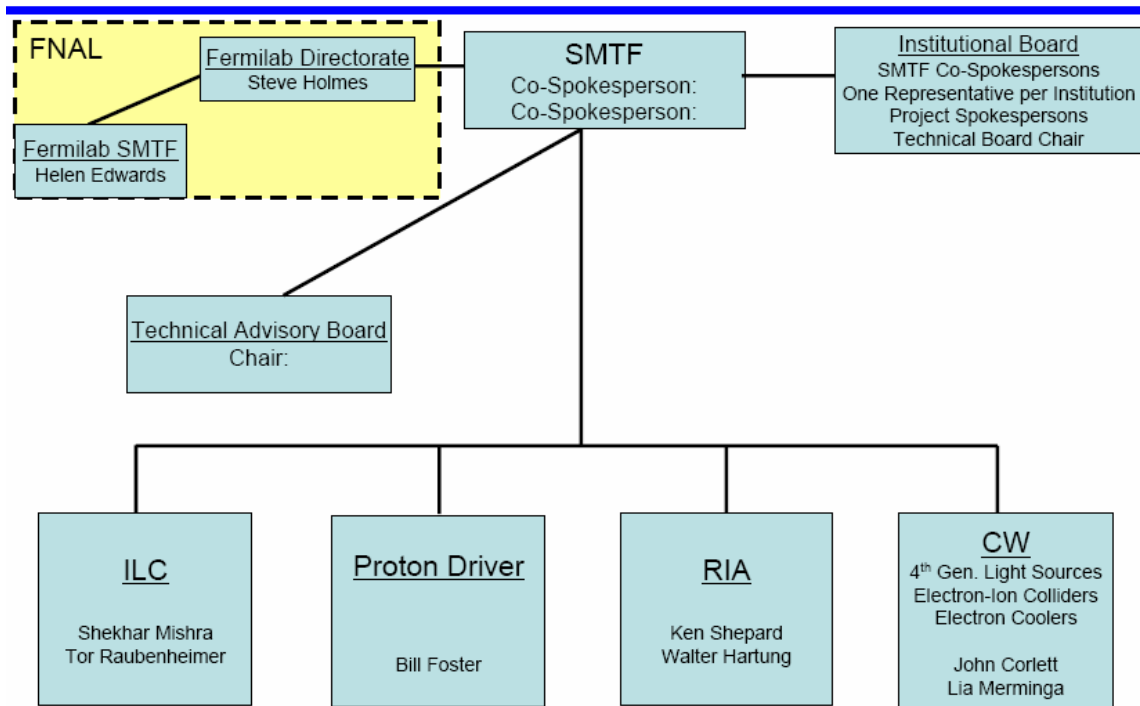
WBS	Description	SMTF Phase	SMTF With Contingency k\$	Totals		FY05		FY06		FY07		FY08		FY09		FY10		FY11		FY12	
				k\$	FTE-y	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE	k\$	FTE
6	Injector & Beam Line		\$ 7,524	\$ 6,019	30	\$ 120	0	\$ 1,114	13	\$ 1,310	0	\$ 710	5	\$ 400	0	\$ 400	0	\$ 1,965	12	\$ -	0
6.1	Injector Phase A	I		\$ 1,983	13	\$ 120	0	\$ 653	13	\$ 1,210	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0
6.2	One module beam line			\$ 461	0	\$ -	0	\$ 461	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0
6.3	Injector Phase B			\$ 660	5	\$ -	0	\$ -	0	\$ -	0	\$ 210	5	\$ 150	0	\$ 150	0	\$ 150	0	\$ -	0
6.4	4 Module Beam Line Upgrade	III		\$ 600	0	\$ -	0	\$ -	0	\$ -	0	\$ 150	0	\$ 150	0	\$ 150	0	\$ 150	0	\$ -	0
6.5	Injector Phase C			\$ 1,565	12	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ 1,565	12	\$ -	0
6.6	3.9 GHz spare klystron			\$ 250	0	\$ -	0	\$ -	0	\$ -	0	\$ 250	0	\$ -	0	\$ -	0	\$ -	0	\$ -	0
6.7	Injector Development			\$ 500	0	\$ -	0	\$ -	0	\$ 100	0	\$ 100	0	\$ 100	0	\$ 100	0	\$ 100	0	\$ -	0

Table 12.7 Summary of the Phtoinjector Hardware Budget and FTE.

## 13. SMTF Organization

The collaboration is in process of forming an SMTF organization. The collaboration will be led by two co-spokespersons, who will chair an Institutional Board, which comprises of one representative per collaborating institutions and the project leaders. The institutional board members have been selected by the collaborating institutes. A Technical Advisory Board will be appointed by the institutional board. The collaboration will interact with the Fermilab management through the Associate Director for Accelerator and Technologies. Fermilab has an internal SMTF organization that has the responsibilities of the infrastructure, day-to-day operation and safety.

### SMTF Organization Chart



#### Fermilab SMTF Organization:

Fermilab has a stated strategy of pursuing International Linear Collider and Proton Driver R&D programs in parallel. Because the two programs are developing implementations based on SRF, the opportunity exists for effective utilization of Fermilab resources through sharing of infrastructure and people. The SMTF will facilitate integration, and become a significant component, of these programs. Because multiple organizations are involved, both within and outside Fermilab, coordination of SRF-based activities from within the Directorate is desirable. The goal is a unified approach that maximizes the effectiveness of available resources.

The Accelerator (AD) and Technical (TD) Divisions are providing, and will continue to provide, the bulk of Fermilab resources in support of the ILC and PD programs. Support from the Particle Physics (PPD) and Computing (CD) Divisions will be encouraged and welcomed to the extent practical. Presently program leaders for both ILC and PD reside in TD. However, as the bulk of Fermilab's accelerator physics and engineering expertise continues to reside in the AD it is important to integrate this effort, as the Run II Upgrade effort starts to roll off, while minimizing the potential impediments imposed by division boundaries. To this end it is proposed to organize and manage the ILC, PD, and SMTF efforts as an integrated activity.

### Goals and Responsibilities

The organizational/management goal is to provide coordination and integration of the three SRF based activities at Fermilab: ILC, PD, and SMTF. A Fermilab organization is proposed in which the Associate Director for Accelerators (ADA) retains responsibility for integration and coordination of Fermilab's SRF based programs: ILC R&D, Proton Driver R&D, and SMTF. Figure 13.1 shows an organization to achieve these aims. This organization represents an integrated line management structure. In interpreting the organization chart "SMTF" refers to the facility in which SRF hardware is tested, ILC refers to the Fermilab based component of the International Linear Collider R&D program, including both SRF and non-SRF components, and "PD" refers to the Fermilab based Proton Driver R&D program, again including both SRF and non-SRF components.

While each programs draws support from across division boundaries, each also has a host division which holds overall responsibility for planning, execution, and reporting against the agreed upon scope of work. The establishment of a host division is intended to enhance, not impede, the integration of effort across division boundaries. TD currently is the host division for ILC and PD, and will remain so for the immediately foreseeable future. AD will assume the responsibility as host division to the SMTF.

The primary mechanism for coordinating these activities will be by a Fermilab SRF Steering Committee consisting of the ADA, the program leaders, the program engineers, the SMTF facilities manager, and the AD and TD heads. The ADA, as chair of the steering committee, and his deputy, hold line management responsibility for all aspects of the SRF based program at Fermilab.

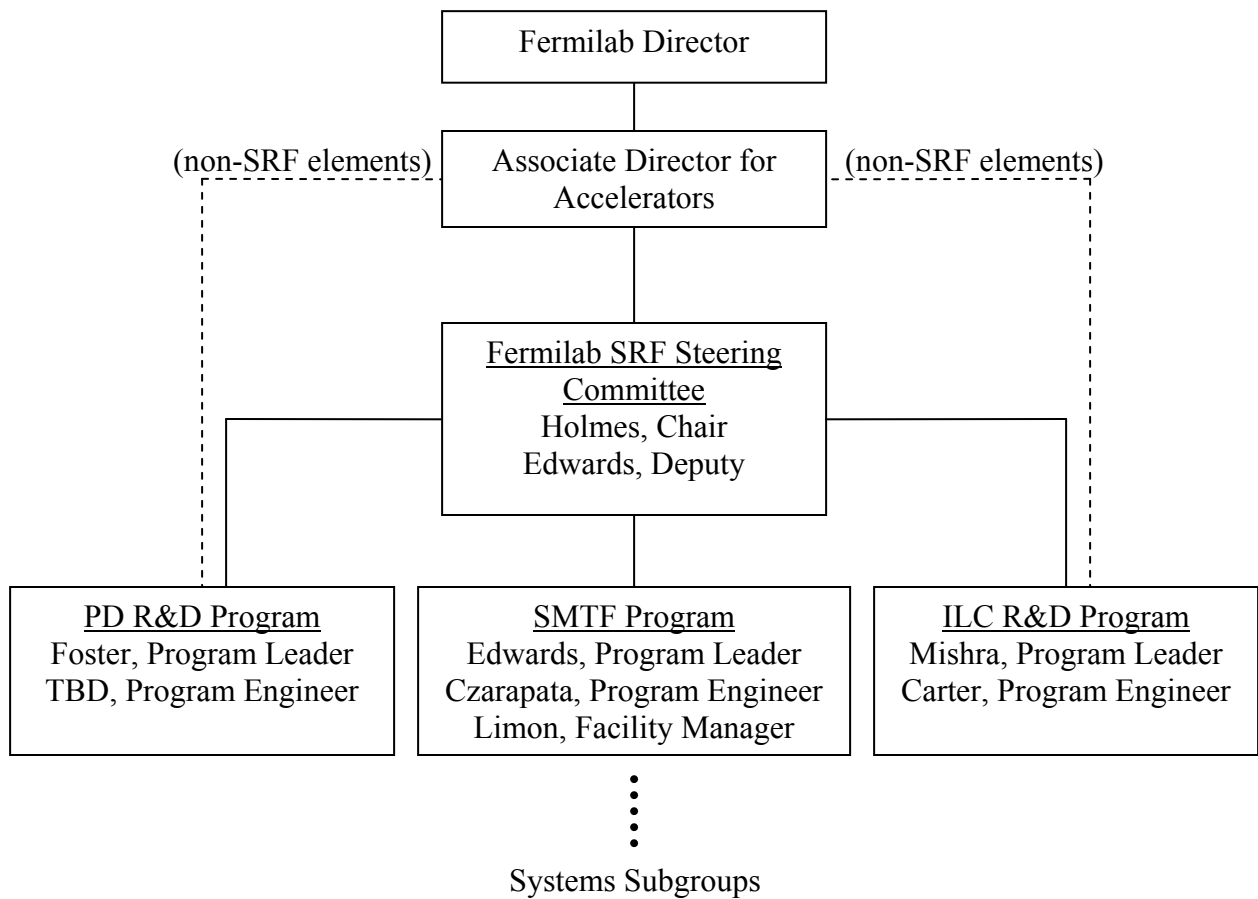


Figure 13.1: Fermilab SRF Organization Chart

## a. International Collaboration on SMTF

The following sections are either summary of our discussions with the institutes and/or have been provided by the institutional representatives.

### INFN

The SMTF management is in discussion with Carlo Pagani (Milano) and Giorgio Bellettini (Pisa) on the possible contribution of INFN to the ILC component of SMTF. More general discussions have taken place with Sergio Bertolucci of Frascati. The initial discussions have identified three possible areas of collaboration; the cryomodule cold mass, a "Chechia" horizontal test facility, and the Low-Level RF.

The primary area of initial interest is the cryomodule cold mass. INFN has been asked to be the lead institution for producing the cold mass. INFN, through the work led by Carlo Pagani and collaborators, are the world's experts in the design and fabrication of the Tesla

Cryomodule used at the DESY Tesla Test Facility. The cold mass consists of all components (structural support backbone and other cryogenic piping, superinsulation, mu-metal, instrumentation etc.) surrounding the dressed cavities including the vacuum vessel. INFN is being asked to share the costs of the materials and engineering with SMTF and to provide the engineering designs. Improvements to the existing design and on where the cold mass will be fabricated are also being discussed. Fabrication may take place in European and US industries. Fermilab will provide engineering assistance to INFN for the modifications to the design of the cold mass.

The detector system and the programmable logic to be designed for real time beam amplitude and phase control by the Low-Level RF seem well tuned to the expertise of the CDF-Pisa group. A possible contribution of that group to this project is being discussed with Giorgio Bellettini and with Luciano Ristori.

## KEK

KEK will collaborate with SMTF in several areas. At present the details of the collaboration are still under discussion and still being worked out. Nevertheless, there is one primary area of interest being discussed that both KEK and SMTF find of mutual benefit. KEK will provide SMTF with up to eight (4 in FY05 and 4 in FY06) SRF cavities fabricated in Japan. These "bare" cavities will likely be of the "high gradient" design. The dressing of the cavities is under discussion. SMTF will assemble the cavities into a string, and insert them into the cold mass and cryomodule and test with beam.

## The TESLA Collaboration

A close association with the Tesla Collaboration is critical to the success of the SMTF. They have agreed to help SMTF with a very open and collaborative spirit. They are providing designs, along with numerous engineering discussions, software, and a cryomodule for testing at SMTF. The makeup of SMTF includes members from the Tesla Collaboration as well as DESY and vice-versa. Joint meetings are underway to discuss the roles and relationship of the two organizations.

## DESY and SMTF

It is recognized that DESY is a key player in successful technology transfer to SMTF. To this end DESY has offered to provide Fermilab (a long term TESLA collaborator) with a Tesla module in the time frame 2006/2007. The integration of this module into the SMTF plan is discussed elsewhere in this proposal.

The DESY management supports the SMTF effort and recognizes the importance of free and open exchange and use of each other's facilities and exchange of personnel. As well, DESY recognizes its essential role toward fostering the start up of regional facilities such as SMTF.

It is expected that as the structure of the ILC GDI is established that a clear picture of the formal international organization of and interplay between the different test facilities will develop. At this juncture DESY believes it is best to continue to collaborate within the framework of the present agreements which have been successful now for the many years of the TESLA collaboration, and to wait for that international structure to evolve in order to formulate the formal structure.

## 14. Summary

The SMTF represents a major new initiative by Fermilab and its national and international collaborators to advance SRF accelerator technology. The SMTF collaboration will fabricate and process SRF accelerating cavities and SRF components in collaboration with industry. The facility would then be used to assemble the cavities into cryomodules (accelerator sub-units), as well as test, and validate the designs with an electron beam. The R&D performed at SMTF will be of value to several planned accelerator projects: The International Linear Collider; Proton Driver; Rare Isotope Accelerator and 4<sup>th</sup> Generation Light Sources. .